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ABSTRACT

This Navy training and self-study manual is designed to provide a basic theoretical and practical understanding of primarily diesel engines and associated equipment, the main emphasis being on shipboard types and operations. Each chapter offers verbal and pictorial description of machinery, with both schematic and equipment-specific depiction of operation. Chapters cover basic reciprocating internal combusion engine theory, parts, operating principles, and mechanisms; engine starting, cooling, and lubricating systems; diesel air and fuel systems; compressed air systems; refrigeration and air conditioning systems; pumps and valves; distilling plants; lathes and lathe machinery operations; propulsion control systems and power transmission. At the end of the text there is a glossary and a series of study assignments, each with its own learning objectives clearly stated, followed by corresponding test questions. The emphasis throughout is on proper maintenance and operation of equipment based on understanding and practical experience. (CP)

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ENGINEMAN 3 & 2

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NAVAL EDUCATION AND TRAINING COMMAND

RATE TRAINING MANUAL AND NONRESIDENT CAREER COURSE

NAVEDTRA 10541-C

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
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Although the words "he", "him", and "his", are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading *Engineman 3 & 2*, NAVEDTRA 10541-C.

PREFACE

This Rate Training Manual and Nonresident Career Course (RTM/NRCC) form a self-study package that will enable Enginemen to acquire the theoretical knowledge and operational skills required to advance to Engineman Third Class and Engineman Second Class. Combined with the necessary practical experience and a review of other applicable training manuals, a knowledge of the information in this self-study package will help the student meet advancement requirements.

Designed for individual study and to support on-the-job training, the RTM provides subject matter that relates directly to the occupational qualifications of the Engineman rating. The NRCC provides the usual way of satisfying the requirements for completing the RTM. The set of assignments in the NRCC includes learning objectives and supporting items designed to lead students through the RTM.

This self-study package was prepared by ENCM C. B. Thayer and ENC C. L. Farris, Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training. Technical assistance was provided by the Naval Schools Command, Great Lakes; Operational Test and Evaluation Force, Norfolk, Virginia and Naval Sea Systems Command.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CREDITS

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CHAPTER 1

ADVANCEMENT

This training manual is designed to help you to increase your knowledge in the various aspects of the Engineman rating and to help you advance in rating to EN3 and EN2. Your contribution to the Navy depends on your willingness and ability to accept increasing responsibilities as you advance in rate. When you assume the duties of an Engineman, you begin to accept certain responsibilities for the work of others. As you advance in your career, you accept responsibilities in military matters as well as in the occupational requirements of the Engineman rating.

ENGINEMAN RATING

The Engineman rating is a general rating; that is, it covers a broad occupational field of related duties and functions.

Enginemen are assigned to all types of ships. On diesel engine propelled ships, most Enginemen are assigned to "M" Division where they operate and maintain ship propulsion machinery and associated equipment such as: pumps, distilling plants, compressors, valves, oil purifiers, heat exchangers, governors, reduction gears, shafts, and shaft bearings.

Enginemen on ships propelled by steam machinery are usually assigned to "A" Division, where they maintain and repair machinery such as: steering engines, anchor windlasses, cranes, winches, elevators, laundry equipment, galley equipment, and air conditioning and refrigeration equipment.

The nature of an Engineman's duties depends largely on the type of ship or station to which assigned. Repair ships and tenders furnish other ships with spare parts, repairs, and other services that are beyond the facilities of the ship's crew. The duties of an Engineman assigned to a repair ship or tender may consist mainly of repairs and other services to ships assigned to the tender or repair ship.

This manual is organized to give you a systematic understanding of your job. The occupational standards used in preparing the text are contained in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* NAVPERS 18068-D. We recommend that you study the Engineman section of NAVPERS 18068-D to gain an understanding of the skills required of an Engineman. Then, study the subject matter carefully. The knowledge you gain will enable you to become a more proficient operator and mechanic, and the Navy will profit from your skills.

As you advance to EN3 and then to EN2, your responsibilities for military leadership will be the same as those of petty officers in other ratings since every petty officer has military as well as technical duties. Your responsibilities for technical leadership will be special to your rating and directly related to your work as an Engineman. Operating and maintaining a ship's engineering plant and associated equipment requires teamwork along with a special kind of leadership that can be developed only by personnel who have a high degree of technical competence and a deep sense of personal responsibility. Strive to improve your leadership and technical knowledge through study, observation, and practical application.

Leadership in a technical field involves more than just giving orders. In fact, you can demonstrate some of the most important aspects of technical leadership even if you are not

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required to tell anyone else what to do. As an EN3 and EN2 you demonstrate technical leadership when you follow orders exactly, when you observe safety precautions, when you accept responsibility, when you continue to increase your knowledge, and when you perform every detail of your work with complete integrity and reliability.

Integrity of work is really a key factor in technical leadership, and all other factors relate to it in some way. Integrity of work is demonstrated in big ways and little ways—the way you stand a messenger watch, the way you maintain your tools and equipment, the way you deal with machinery failures and casualties, and the way you wipe up deckplates. When you perform every job just as well as you can, and when you constantly work to increase your knowledge, you demonstrate integrity of work in a concrete, practical, everyday sort of way. When your work has integrity, you are demonstrating technical leadership.

NAVY ENLISTED CLASSIFICATION CODES

The Engineman rating is a source of a number of Navy Enlisted Classification Codes (NEC's). NEC's reflect special knowledge and skill in certain ratings. The NEC coding system is a form of management control over enlisted skills. It identifies skills and training required for specific types of operations or equipment. The Chief of Naval Personnel details personnel who have acquired those skills to those ships that require the skills. There are a number of NEC's that Enginemen may earn at certain grade levels by satisfactorily completing an applicable course of instruction at a Navy school. Your personnel office will have complete information on NEC's and qualification procedures.

THE NAVY ENLISTED ADVANCEMENT SYSTEM

Some of the things you gain through advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

But the advantages of advancing in rate are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement, you increase your value to the Navy in two ways. First, you become more valuable as a specialist in your own rating. And second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

The basic ideas behind the advancement system have remained stable for many years, but specific portions may change rather rapidly. It is important that you know the system and follow changes carefully. BUPERS Notices in the 1418 series will normally keep you up-to-date.

The normal system of advancement may be easier to understand if it is broken into two parts:

1. Those requirements that must be met before you may be considered for advancement.
2. Those factors that actually determine whether you will be advanced.

QUALIFYING FOR ADVANCEMENT

In general, to qualify (be considered) for advancement, you must:

1. Have a certain amount of time in paygrade.
2. Demonstrate knowledge of material in your mandatory Rate Training Manuals by achieving a suitable score on your command's test, by successfully completing the associated Nonresident Career Courses or, in some cases, by successfully completing an appropriate Navy school.
3. Demonstrate ability to perform the Personnel Advancement Requirement (PAR) Program, NAVPERS 1414/4.
4. Be recommended by your commanding officer.
5. For petty officer third class and second class candidates ONLY, demonstrate knowledge of military subjects by passing a locally administered military/leadership examination

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based on the naval standards for advancement (from NAVPERS 18068 series).

6. Demonstrate knowledge of the technical aspects of your rate by passing a Navywide advancement examination based on the occupational standards applicable to your rate (from NAVPERS 18068 series, those standards listed at and below your rate level).

Figure 1-1 is a detailed view of the requirements for advancement of active duty personnel and figure 1-2 is similar information for inactive duty personnel. Remember that the occupational standards can change. Check with your division officer or training officer to be sure that you know the most recent standards.

If you meet all of the above requirements satisfactorily, you become a member of the group from which advancements will be made.

WHO WILL BE ADVANCED?

Advancement is not automatic. Meeting all of the requirements makes you eligible but does not guarantee your advancement. Some of the factors that determine which persons of all of those qualified will actually be advanced in rate are:

1. The score made on the advancement examination.
2. The length of time in service.
3. The performance marks earned.
4. The number of vacancies being filled in a given rate.

If the number of vacancies in a given rate exceeds the number of qualified personnel, then all of those qualified will be advanced. More often, there are more qualified people than there are vacancies. When this happens, the Navy advances those who are BEST qualified by combining three personnel evaluation systems:

1. Merit rating system (annual evaluation and commanding officer recommendation).
2. Personnel testing system (advancement examination score—with some credit for passing previous advancement exams).
3. Longevity (seniority) system (time in rate and time in service).

Simply stated, each individual is given credit for what he or she has achieved in the three series of performance, knowledge, and seniority. A composite, known as the final multiple score, is derived from these three factors. All of the candidates who have passed the examination from a given advancement population are then placed on one list. Based on the final multiple score the person with the highest multiple score is ranked first, and so on, down to the person with the lowest multiple score. Advancement authorizations are then issued for candidates for E-4, E-5, and E-6, beginning at the top of the list, for the number of persons needed to fill the existing vacancies. Candidates for E-7 whose final multiple scores are high enough will be designated PASS SELBD ELIG (Pass Selection Board Eligible). Their names will be placed before the Chief Petty Officer Selection Board, a BUPERS board charged with considering all designated eligible candidates for advancement to CPO. Advancement authorizations for those being advanced to CPO are issued by this board.

Who, then, are the individuals who are advanced? Basically, they are the ones who achieved the most in preparing for advancement. They were not content to just qualify; they went the extra mile in their training. Through that training and their work experience they developed greater skills, learned more, and accepted more responsibility. While it cannot guarantee that any one person will be advanced, the advancement system does guarantee that all persons within a particular rate will compete equally for the vacancies that exist.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement?

1. Learn the naval standards for your paygrade level.
2. Learn how to perform the work defined by the occupational standards for your rating.
3. Work on the Personnel Advancement Requirement (PAR) Program for your rating.
4. Study the required rate training manuals for your rating.

REQUIREMENTS*	E1 to E2	E2 to E3	#E3 to E4	#E4 to E5	E5 to E6	##†E6 to E7	##†E7 to E8	##†E8 to E9
SERVICE	6 mos. service.	6 mos. as E-2.	6 mos. as E-3. 2 years time in service.	12 mos. as E-4. 3 years time in service.	24 mos. as E-5. 7 years time in service.	36 mos. as E-6. 10 years time in service.	36 mos. as E-7. 8 of 13 years time in service must be enlisted.	36 mos. as E-8. 10 of 16 years time in service must be enlisted.
SCHOOL	Recruit Training. (C.O. may advance up to 10% of graduating class.)		Class A for PR3, DT3, IS3, AME3, HM3, FTB3, MT3, MU3, EW3	Naval Justice School LN2		Navy School for AGC, MUC.††		
PERSONNEL ADVANCEMENT REQUIREMENT (PAR) NAVPERS 1414/4			Personnel Advancement Requirement (PAR) must be completed for advancement to E-4 through E-7.					
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS**	Locally prepared tests.	See below.	Navywide examinations required for all PO advancements.			Navywide selection board.		
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NAVEDTRA 10052 (current edition).					Nonresident career courses and recommended reading. See NAVEDTRA 10052 (current edition).	
AUTHORIZATION	Commanding Officer		NAVEDTRAPRODEVCEN					

*All advancements require commanding officer's recommendation.

†2 years obligated service required for E-7, E-8, and E-9.

#Military leadership exam required for E-4 and E-5.

**For E-2 to E-3, NAVEDTRAPRODEVCEN exams or locally prepared tests may be used.

††Waived for qualified EOD personnel.

##Advancement to E-7 will be 10 years TIS effective 1 January 1979; to E-8, 13 years TIS effective 1 November 1978; to E-9, 16 years TIS effective 1 November 1978.

Figure 1-1.—Active duty advancement requirements.

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	6 mos.	6 mos.	6 mos.	12 mos.	24 mos.	36 mos. with total 9 yrs service.	36 mos. with total 12 yrs service.	24 mos. with total 15 yrs service.
TOTAL TRAINING DUTY IN GRADE†	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PERSONNEL ADVANCEMENT REQUIREMENT (PAR) NAVPERS 1414/4			Personnel Advancement Requirements (PAR) NAVPERS 1414/4 must be completed for advancement to E4 through E7.					
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam		Standard Exam required for all PO advancements. Also pass Military Leadership Exam for E4 and E5.				Standard Exam Selection Board.	
AUTHORIZATION	Commanding Officer		NAVEDTRAPRODEVCEN					

*Recommendation by commanding officer required for all advancements.
†Active duty periods may be substituted for training duty.

Figure 1-2.—Inactive duty advancement requirements.

5. Study other material applicable for advancement in your rating such as shown in the *Bibliography for Advancement Study*, NAVEDTRA 10052. (NOTE: If you are working for advancement to second class, remember that you may be examined on third class standards as well as on second class standards).

The following sections describe these five factors and give you some practical suggestions on how to use them in preparing for advancement.

Naval Standards

Naval standards are requirements that apply to all ratings rather than to any one particular rating. Naval requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watchstanding, and other subjects which are required of petty officers in all ratings.

You are required to pass a Navywide military/leadership examination for E-4 or E-5, as appropriate, before you take the occupational examinations. The military/leadership examinations are administered on a schedule determined by your commanding officer. Candidates are required to pass the applicable military/leadership examination only once. Each of these examinations consists of 100 questions based on information contained in *Military Requirements for Petty Officers 3 & 2*, NAVEDTRA 10056 (current edition) and in other publications listed in the *Bibliography for Advancement Study*, NAVEDTRA 10052 (current edition).

Occupational Standards

Occupational Standards are requirements that are directly related to the work of each rating.

Both the naval standards or requirements and the occupational standards are divided into subject matter groups.

The *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068-D has replaced the "quals manual" and the NEC manual. Section I contains the occupational and naval standards for advancement to each paygrade in each enlisted rating. Section II contains the Navy Enlisted Classification Codes.

Advancement Examinations

The Navywide advancement examinations for paygrades E-4 and E-5 contain 150 questions related to the occupational areas of your rating.

On the day you take your advancement examination, your examination proctor will announce that you are to remove the last sheet of your test booklet and give it to him. This last page of your booklet is the Exam Information Sheet, shown in figure 1-3, and on the reverse side is the Profile Form Information Sheet, shown in figure 1-4. When you turn in your examination, the sheet will be returned for you to keep.

Several weeks following your examination, you should receive a profile card similar to the one shown inside the black frame in figure 1-4. Suppose your profile card (fig. 1-4) shows a "P" on section 5 (see the arrow) of the examination; you should then refer back to the Exam Information Sheet, figure 1-3. If you then compared section 5 on the profile card to the section of figure 1-3 marked by the marginal arrow, you would find the subject, Air Conditioning and Refrigeration. Since you had received a "P" for poor on this section, study would appear necessary on that subject and standards before your next examination.

Your Education Services Officer should be able to furnish you with a standards and bibliography sheet for each examination you are to take. This bibliography will cite the publications used in examination development. These sheets along with your profile card and Exam Information Sheet will help you plan your study for examinations.

PERSONNEL ADVANCEMENT REQUIREMENT (PAR) PROGRAM, NAVPERS 1414/4

The Personnel Advancement Requirement (PAR) is a new system of evaluation that replaces the *Record of Practical Factors*, NAVEDTRA 1414/4. The PAR is based on the

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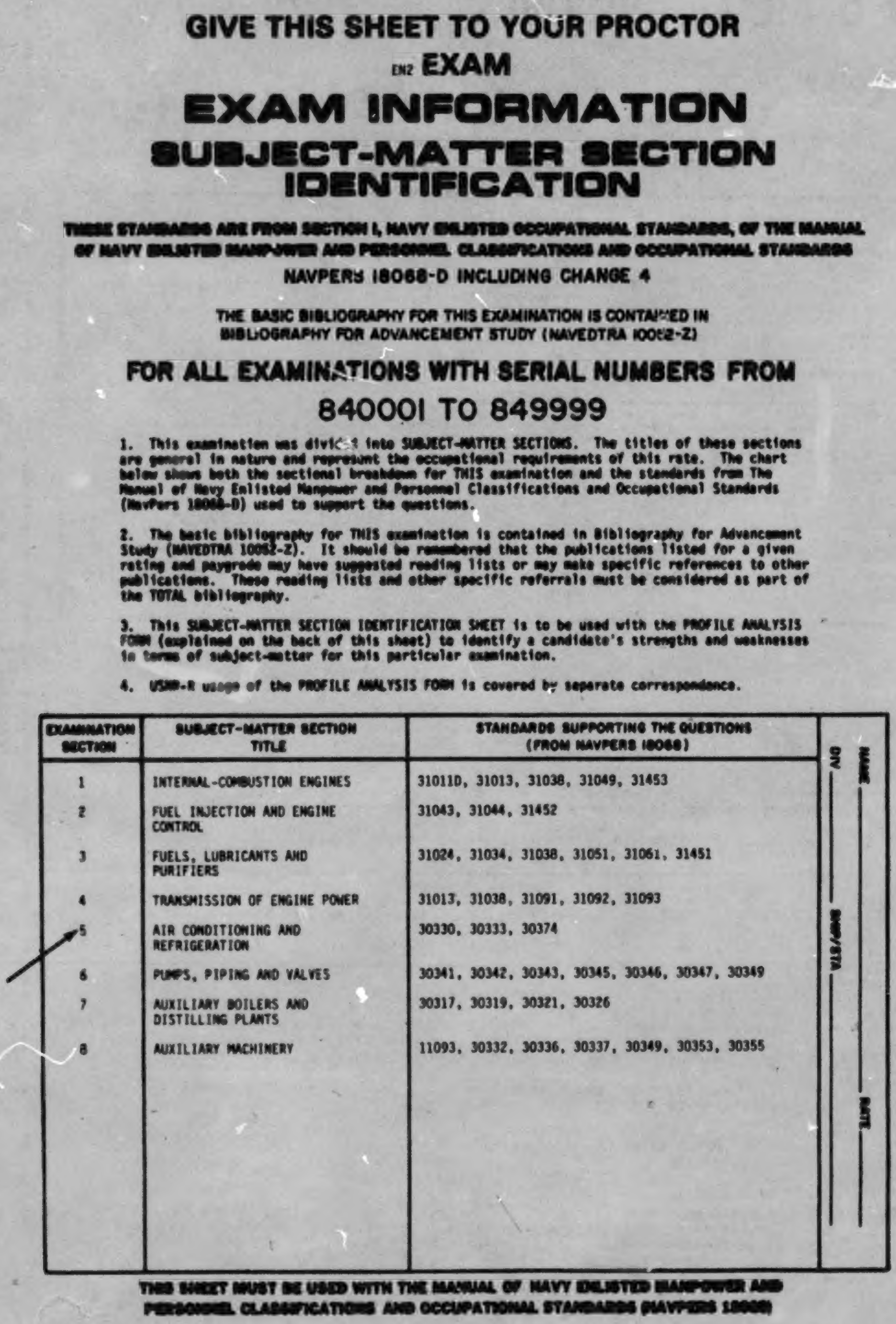


GIVE THIS SHEET TO YOUR PROCTOR

EN2 EXAM

EXAM INFORMATION

SUBJECT-MATTER SECTION IDENTIFICATION

THESE STANDARDS ARE FROM SECTION I, NAVY ENLISTED OCCUPATIONAL STANDARDS, OF THE MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS

NAVPERS 18068-D INCLUDING CHANGE 4

THE BASIC BIBLIOGRAPHY FOR THIS EXAMINATION IS CONTAINED IN BIBLIOGRAPHY FOR ADVANCEMENT STUDY (NAVEDTRA 10052-Z)

FOR ALL EXAMINATIONS WITH SERIAL NUMBERS FROM

840001 TO 849999

1. This examination was divided into SUBJECT-MATTER SECTIONS. The titles of these sections are general in nature and represent the occupational requirements of this rate. The chart below shows both the sectional breakdown for THIS examination and the standards from The Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards (NavPers 18068-D) used to support the questions.

2. The basic bibliography for THIS examination is contained in Bibliography for Advancement Study (NAVEDTRA 10052-Z). It should be remembered that the publications listed for a given rating and paygrade may have suggested reading lists or may make specific references to other publications. These reading lists and other specific referrals must be considered as part of the TOTAL bibliography.

3. This SUBJECT-MATTER SECTION IDENTIFICATION SHEET is to be used with the PROFILE ANALYSIS FORM (explained on the back of this sheet) to identify a candidate's strengths and weaknesses in terms of subject-matter for this particular examination.

4. USNR-R usage of the PROFILE ANALYSIS FORM is covered by separate correspondence.

EXAMINATION SECTION	SUBJECT-MATTER SECTION TITLE	STANDARDS SUPPORTING THE QUESTIONS (FROM NAVPERS 18068)
1	INTERNAL-COMBUSTION ENGINES	31011D, 31013, 31038, 31049, 31453
2	FUEL INJECTION AND ENGINE CONTROL	31043, 31044, 31452
3	FUELS, LUBRICANTS AND PURIFIERS	31024, 31034, 31038, 31051, 31061, 31451
4	TRANSMISSION OF ENGINE POWER	31013, 31038, 31091, 31092, 31093
5	AIR CONDITIONING AND REFRIGERATION	30330, 30333, 30374
6	PUMPS, PIPING AND VALVES	30341, 30342, 30343, 30345, 30346, 30347, 30349
7	AUXILIARY BOILERS AND DISTILLING PLANTS	30317, 30319, 30321, 30326
8	AUXILIARY MACHINERY	11093, 30332, 30336, 30337, 30349, 30353, 30355

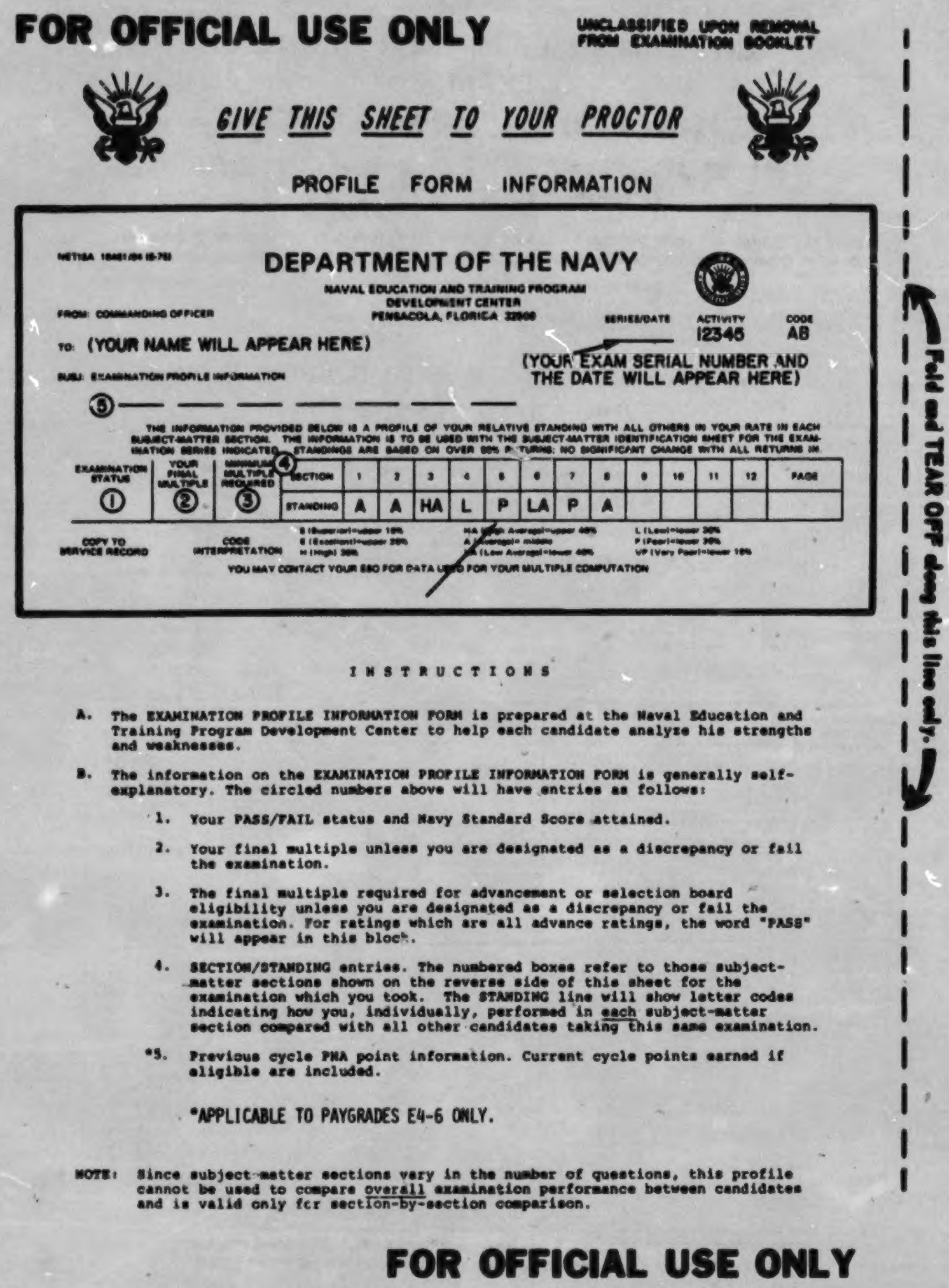
NAME ________________ RATE ________________

DIV ________________ SHIP/STA ________________

THIS SHEET MUST BE USED WITH THE MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS (NAVPERS 18068)

75.236

Figure 1-3.—Exam Information Sheet.



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PROFILE FORM INFORMATION

NETISA 1640/04 (6-75)

DEPARTMENT OF THE NAVY
NAVAL EDUCATION AND TRAINING PROGRAM
DEVELOPMENT CENTER
PENSACOLA, FLORIDA 32509

FROM: COMMANDING OFFICER

TO: (YOUR NAME WILL APPEAR HERE)

SUBJ: EXAMINATION PROFILE INFORMATION

SERIES/DATE	ACTIVITY	CODE
	12345	AB

(YOUR EXAM SERIAL NUMBER AND THE DATE WILL APPEAR HERE)

⑤ ___ ___ ___ ___ ___ ___ ___

THE INFORMATION PROVIDED BELOW IS A PROFILE OF YOUR RELATIVE STANDING WITH ALL OTHERS IN YOUR RATE IN EACH SUBJECT-MATTER SECTION. THE INFORMATION IS TO BE USED WITH THE SUBJECT-MATTER IDENTIFICATION SHEET FOR THE EXAMINATION SERIES INDICATED. STANDINGS ARE BASED ON OVER 90% RETURNS; NO SIGNIFICANT CHANGE WITH ALL RETURNS IN.

EXAMINATION STATUS	YOUR FINAL MULTIPLE	MINIMUM MULTIPLE REQUIRED	④ SECTION	1	2	3	4	5	6	7	8	9	10	11	12	PAGE
①	②	③	STANDING	A	A	HA	L	P	LA	P	A					

COPY TO SERVICE RECORD

CODE INTERPRETATION
S (Superior)=upper 10%
E (Excellent)=upper 25%
H (High) 30%
HA (High Average)=upper 40%
A (Average)= middle
LA (Low Average)=lower 40%
L (Low)=lower 30%
P (Poor)=lower 30%
VP (Very Poor)=lower 10%

YOU MAY CONTACT YOUR ESO FOR DATA USED FOR YOUR MULTIPLE COMPUTATION

Fold and TEAR OFF along this line only.

INSTRUCTIONS

A. The EXAMINATION PROFILE INFORMATION FORM is prepared at the Naval Education and Training Program Development Center to help each candidate analyze his strengths and weaknesses.

B. The information on the EXAMINATION PROFILE INFORMATION FORM is generally self-explanatory. The circled numbers above will have entries as follows:

1. Your PASS/FAIL status and Navy Standard Score attained.
2. Your final multiple unless you are designated as a discrepancy or fail the examination.
3. The final multiple required for advancement or selection board eligibility unless you are designated as a discrepancy or fail the examination. For ratings which are all advance ratings, the word "PASS" will appear in this block.
4. SECTION/STANDING entries. The numbered boxes refer to those subject-matter sections shown on the reverse side of this sheet for the examination which you took. The STANDING line will show letter codes indicating how you, individually, performed in each subject-matter section compared with all other candidates taking this same examination.

*5. Previous cycle PNA point information. Current cycle points earned if eligible are included.

*APPLICABLE TO PAYGRADES E4-6 ONLY.

NOTE: Since subject-matter sections vary in the number of questions, this profile cannot be used to compare overall examination performance between candidates and is valid only for section-by-section comparison.

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Figure 1-4.—Profile Form Information Sheet.

new occupational standards and is presented in task statements, whereas the old *Record of Practical Factors* was stated in terms of practical factors and knowledge factors which required lengthy and detailed checkoff lists. The PAR allows a command to evaluate the overall abilities of an individual in a day-to-day work situation.

The E-8 and E-9 paygrades are exempted from the program because there are other means of selection for advancement to these paygrades. Also, the E-3 apprenticeships are so broad that it is impractical to develop a single PAR for this paygrade.

The PAR for each rating lists the requirements for advancement to paygrades E-4 through E-7 in one pamphlet. The PAR is comprised of three sections which contain descriptive information, instructions for administration, special rating requirements, and advancement requirements.

Section I–Administration Requirements–contains the individual's length of service, time in paygrade, and a checkoff for the individual's having passed the E-4/E-5 military/leadership examination.

Section II–Formal School and Training Requirements–contains a checkoff entry for the individual's having completed the Military Requirements Navy Training Course and the applicable Navy Training Course for the rating.

Section III–Occupational and Military Ability Requirements–is a checkoff list of task statements. Items in this section are to be interpreted broadly and do not demand actual demonstration of the item nor completion of alternate local examination, although demonstration is a command prerogative. Individuals are evaluated by observation of their ability to perform tasks in related areas by training received or, if desired, by demonstration.

PAR forms are stocked in the Navy Supply System.

ENGINEERING OPERATIONAL SEQUENCING SYSTEM (EOSS)

The purpose of EOSS is to detail the sequential operational functions for the complete cycle of plant evolutions. Each plant evolution becomes a plant procedure which is supplied to the Engineering Officer of the Watch. The use of correct operating and casualty control techniques should reduce casualties resulting from personnel error and increase equipment use and life.

If EOSS is followed, all watchstanding will be improved and standardized, and watchstanders will develop and maintain maximum proficiency in engineering operation and casualty control procedures. These improvements will contribute to the operational readiness of the engineering propulsion plant.

EOSS has a secondary feature in that it is an excellent aid for indoctrinating and training newly assigned engineering personnel, providing training for advancement in rating, and preparing for refresher training. This training, in turn, will also help to assure the overall operational readiness of the engineering propulsion plant.

EOSS is broken down into two subdivisions: Engineering Operational Procedures (EOP) and Engineering Operational Casualty Control (EOCC).

Since EOSS is tailored for each particular ship, complete details are not given in this training manual. For complete information, study the EOSS provided for your ship. It is a ready reference.

PERSONNEL QUALIFICATION STANDARDS

The Personnel Qualification Standard is a document which describes the knowledge and skills a trainee must have to perform certain duties. It will speed up learning progress since each person will know exactly what information to obtain to prepare for qualifying in increasingly complex duties. It individualizes learning so that each person may take advantage of opportunities to learn on the job. It places the responsibilities for learning on the learner and continuously monitors achievement. By providing a convenient record of accomplishment, it offers a means whereby supervisors can check individual ability and progress.

Since the Personnel Qualification Standards have been assembled by groups of experienced officers and petty officers, they attempt to represent the guidance which would be furnished if each person had an experienced and concerned petty officer guiding each step.

Personnel Qualification Standards are designed to support advancement in rating requirements as stated in the *Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* (NAVPERS 18068 series.)

Every Personnel Qualification Standard contains the following sections:

1. Introduction
2. Glossary of Qualification Standard Terms
3. Table of Contents
4. 100 series–Theory
5. 200 series–Systems
6. 300 series–Watchstanding
7. 400 series–Qualification Cards
8. Bibliography
9. Feedback Forms

PURPOSES, BENEFITS, AND LIMITATIONS OF THE PLANNED MAINTENANCE SYSTEM

PURPOSES

The Planned Maintenance System (PMS) was established for several purposes:

1. To reduce complex maintenance to simplified procedures that are easily identified and managed at all levels.
2. To define the minimum planned maintenance required to schedule and control PMS performances.
3. To describe the methods and tools to be used.
4. To provide for the detection and prevention of impending casualties.
5. To forecast and plan manpower and material requirements.
6. To plan and schedule maintenance tasks.
7. To estimate and evaluate material readiness.
8. To detect areas requiring additional or improved personnel training and/or improved maintenance techniques or attention.
9. To provide increased readiness of the ship.

BENEFITS

PMS is a tool of command. By using PMS, the commanding officer can readily determine whether the ship is being properly maintained. Reliability is intensified. Preventive maintenance reduces the need for major corrective maintenance, increases economy, and saves the cost of repairs.

PMS assures better records, containing more data that can be useful to the shipboard maintenance manager. The flexibility of the system allows for programming of inevitable changes in employment schedules, thereby helping to better plan preventive maintenance.

Better leadership and management can be realized by reducing frustrating breakdowns and irregular hours of work. PMS offers a means of improving morale and thus enhances the effectiveness of all hands.

LIMITATIONS OF PMS

The Planned Maintenance System is not self-starting; it will not automatically produce good results; considerable professional guidance is required. Continuous direction at each echelon must be maintained, and one individual must be assigned both the authority and the responsibility at each level of the system's operation.

Training in the maintenance steps as well as in the system will be necessary. No system is a substitute for the actual technical ability required of the petty officers who direct and perform the upkeep of the equipment.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the naval requirements for advancement and the occupational standards of your rating.

In this section we shall discuss most of the publications you will use. The detailed information you need for advancement and for everyday work is contained in them. Some are subject to change or revision from time to time–some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work or to advance in rating. At best, it is a waste of time; at worst, it is likely to be dangerously misleading.

NAVEDTRA PUBLICATIONS

The Naval Education and Training Support Command and its field activities come directly under the command of the Chief of Naval Education and Training instead of the Chief of Naval Personnel. Training materials published by the Naval Education and Training Command are designated as NAVEDTRA. NAVTRA and NAVPERS designators on publications will remain as originally assigned. The designators of publications printed hereafter will be changed to NAVEDTRA as each publication is revised.

The naval training publications described herein include some that are absolutely essential for anyone seeking advancement and some that, although not essential, are extremely helpful.

NAVEDTRA 10052

Bibliography for Advancement Study, NAVEDTRA 10052 is a very important publication for any enlisted person preparing for advancement. It lists required and recommended rate training manuals and other reference materials to be used in preparation for advancement.

NAVEDTRA 10052 is revised and issued annually by the Chief of Naval Education and Training. Each revised edition is identified by a letter following the NAVEDTRA number. When using this publication, be sure that you have the most recent edition.

If extensive changes in standards occur in any rating between the annual revisions of NAVEDTRA 10052, a supplementary list of study material may be issued in the form of a BUPERS Notice. When you are preparing for advancement, check to see whether changes have been made in the standards for your rating. If changes have been made, see whether a BUPERS Notice has been issued to supplement NAVEDTRA 10052 for your rating.

The required and recommended references are listed by paygrade in NAVEDTRA 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class, but remember that you are also responsible for the references listed at the third class level.

In using NAVEDTRA 10052, you will notice that some rate training manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY–that is, you must complete it at the indicated rate level before you can be eligible to take the Navywide examination for advancement. Each mandatory manual may be completed by (1) passing the appropriate nonresident career course that is based on the mandatory training manual; (2) passing locally prepared tests based on the information given in the training manual; or (3) in some cases, successfully completing an appropriate naval school.

Do not overlook the section of NAVEDTRA 10052 which lists the required and recommended references relating to the naval standards for advancement. Personnel of ALL ratings must complete the mandatory military requirements training manual for the appropriate rate level before they are eligible to advance.

The references in NAVEDTRA 10052 which are recommended but not mandatory should also be studied carefully. All references listed in NAVEDTRA 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Besides training manuals, NAVEDTRA 10052 lists official publications on which you may be examined. You should study the sections required, and also become as familiar as possible with all publications you use.

Rate Training Manuals

There are two general types of rate training manuals. RATING manuals (such as this one) are prepared for most enlisted ratings. A rating manual gives information that is directly related to the occupational standards on one rating. SUBJECT MATTER manuals or BASIC manuals give information that applies to more than one rating.

Rate training manuals are revised from time to time to keep them up-to-date technically. The revision of a rate training manual is identified by a letter following the NAVEDTRA number. You can tell whether any particular copy of a training manual is the latest edition by checking the NAVEDTRA number and the letter following this number in the most recent edition of *List of Training Manuals and Correspondence Courses*, NAVEDTRA 10061. (NAVEDTRA 10061 is actually a catalog that lists all current training manuals and courses; you will find this catalog useful in planning your study program.)

Each time a rate training manual is revised, it is brought into conformance with the official publications and directives on which it is based. However, during the life of any edition of a rate training manual, changes will be made to the official sources and discrepancies will arise. In the performance of your duties, you should always refer to the appropriate official publication or directive. If the official source is listed in NAVEDTRA 10052, the Naval Education and Training Program Development Center uses it as a source of questions in preparing the fleetwide examinations for advancement. In case of discrepancy between any publications listed in NAVEDTRA 10052 for a given rate, the examination writers will use the most recent material.

Rate training manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this manual and other Navy training publications when you prepare for advancement.

1. Study the naval standards and the occupational standards for your rating before you study the training manual and refer to the standards frequently as you study. Remember, you are studying the manual primarily to meet these standards.
2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can plan to study at the same time each day. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.
3. Before you begin to study any part of the manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book without any particular plan. Look at the illustrations and read bits here and there as you see things that interest you. Review the Glossary (Appendix I), which provides definitions that apply to words or terms as they are used within the engineering field and within the text. There are many words with more than one meaning. Do not assume that you know the meaning of a word! As you study, if you cannot recall the use of a word, look it up in the Glossary. A table of conversion to the metric system appears in Appendix II for your convenience.
4. Look at the training manual in more detail to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. In this manner you will get a pretty clear picture of the scope and content of the book. As you look through the book, ask yourself some questions:

What do I need to learn about this?
What do I already know about this?
How is this information related to information given in other chapters?
How is this information related to the occupational standards?

5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each

study period, try to cover a complete unit–it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will vary. If you know the subject well or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit–chapter, section, or subsection–write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the training manual, write down the main ideas that you have gotten from studying this unit. Don't just quote the book. If you can't give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use nonresident career courses whenever you can. The courses are based on rate training manuals or on other appropriate texts. As mentioned before, completion of a mandatory rate training manual can be accomplished by passing a nonresident career course based on the rate training manual. You will probably find it helpful to take other courses, as well as those based on mandatory manuals. Taking a course helps you to master the information given in the training manual and also helps you to see how much you have learned.

10. Think of your future as you study rate training manuals. You are working for advancement to third class or second class right now, but some day you will be working toward higher rates. Anything extra that you can learn now will also help you later.

Other NAVEDTRA Publications

Some additional NAVEDTRA publications that you may find useful are listed and described in the following paragraphs. In addition, you may find it useful to consult the training manuals prepared for other ratings in Occupational Fields 3 and 4 (Engineering and Hull). Reference to these training manuals will add to your knowledge of the duties of others in the engineering department.

Another publication you will find of value is *The Metric System* (NAVEDTRA 475-01-00-75-1) which is packaged with a self-study course. Over the next few years, the metric system will become more used by the Navy as well as by the civilian world. You will find it easy to work with once you have mastered the basic terms. It will be difficult to translate values from our present system to the metric system, but this operation will become unnecessary once the new measurements are totally adopted. See your Education Services Officer for information on how to obtain this study package.

NAVSEA PUBLICATIONS

The publications issued by the Naval Sea Systems Command are of particular importance to engineering department personnel. Although you do not need to know everything in these publications, you should have a general idea of where to find the information contained therein.

Naval Ships' Technical Manual

The *Naval Ships' Technical Manual* is the basic engineering doctrine publication of the Naval Sea Systems Command. The manual is kept up-to-date by means of quarterly changes. As new chapters are issued they are being designated by a new quarter numbering system.

The following chapters of the *Naval Ships' Technical Manual* are of particular importance to Enginemen; both the new and old number for each chapter are listed.

NEW	OLD	CHAPTER
078	(9950)	Gaskets and Packing
079(3)	(9880, Sec. III)	Engineering Casualty Control
220	(9560, Vol I)	Boiler Water/Feedwater
220	(9560, Vol II)	Water Chemistry Test & Treatment
233	(9412)	Diesel Engines
241	(9420)	Reduction Gears
244	(9431)	Bearings
262	(9450)	Lubricating Oils, Greases, and Hydraulic Fluids and Lubricating Systems
503	(9470)	Pumps
505	(9480)	Piping Systems
510	(9380)	Ventilating, Heating, Air Conditioning
516	(9590)	Refrigeration Systems
531	(9580)	Distilling Plants
541	(9550)	Fuel Oil Stowage & Equipment
551	(9490)	Compressed Air Plants
556	(9210)	Hydraulic Equipment
562	(9220)	Surface Ship Steering Systems
593	(None)	Pollution Control

NAVSEA Journal

The *NAVSEA Journal* is a monthly publication that contains interesting and useful articles on all aspects of shipboard engineering. This magazine is particularly useful because it presents information that supplements and clarifies information contained in the *Naval Ships' Technical Manual.* It is also of considerable interest because it presents information on new developments in naval engineering. The *NAVSEA Journal* was formerly known as the *Naval Ship Systems Command Technical News.*

The manufacturers' technical manuals furnished with most machinery units and many items of equipment are valuable sources of information on construction, operation, maintenance, and repair. The manufacturers' technical manuals that are furnished with most shipboard engineering equipment are given NAVSHIPS numbers.

Drawings

Some of your work as an Engineman requires an ability to read and work from mechanical drawings. You will find information on how to read and interpret drawings in *Blueprint Reading and Sketching,* NAVEDTRA 10077 (with changes).

In addition to knowing how to read drawings, you must know how to locate applicable drawings. For some purposes, the drawings included in the manufacturers' technical manuals for the machinery or equipment may give you the information you need. In many cases, however, you will find it necessary to consult the onboard drawings. The onboard drawings, which are sometimes referred to as ship's plans or ship's blueprints, are listed in an index called the ship drawing index (SDI). The SDI lists all working drawings that have a NAVSHIPS drawing number, all manufacturers' drawings designated as certification data sheets, equipment drawing lists, and assembly drawings that list detail drawings. The onboard drawings are identified in the SDI by an asterisk (*).

Drawings are listed in numerical order in the SDI. Onboard drawings are filed according to numerical sequence. There are two types of numbering systems in use for drawings that have NAVSEA numbers. The older system is an S-group numbering system. The newer system, used on all NAVSHIPS drawings since 1 January 1967, is a consolidated index numbering system. A cross-reference list of S-group numbers and consolidated index numbers is given in *NAVSEA Consolidated Index of Materials and Services Related to Construction and Conversion,* NAVSEA 0902-LP-002-2000.

ENGINEERING HANDBOOKS

For certain types of information, you may need to consult various kinds of engineering handbooks–mechanical engineering handbooks, marine engineering handbooks, piping handbooks, machinery handbooks, and other handbooks that provide detailed, specialized technical data. Most engineering handbooks contain a great deal of technical information, much of it arranged in charts or tables. To make the best use of engineering handbooks, use the table of contents and the index to locate the information you need.

CHAPTER 2

RECIPROCATING INTERNAL-COMBUSTION ENGINE

The engines with which you will be working convert heat energy into work by burning fuel in a confined chamber; thus the term INTERNAL COMBUSTION. Since the pistons in diesel and gasoline engines employ a back-and-forth motion, they are also classified as RECIPROCATING engines. The occupational standards for advancement in your rate require you to know a great deal about engines of this type. Some of the required knowledge was introduced and explained in the training manual, *Fireman*, NAVEDTRA 10520-E. This chapter provides additional information to help you in understanding the differences between the various types of engines and the principles by which an engine operates.

CYCLES OF OPERATION

The operation of an engine involves the admission of fuel and air into a combustion space and the compression and ignition of the charge. The resulting combustion releases gases and increases the temperature within the space. As temperature increases, pressure increases and forces the piston to move. The movement is transmitted through specially designed parts to a shaft. The resulting rotary motion of the shaft is used for work; thus, heat energy is transformed into rotary mechanical energy. In order for the process to be continuous, the expanded gases must be removed from the combustion space, a new charge must be admitted, and combustion must be repeated.

Table 2-1.—The Events of Their Sequence in a Cycle of Operation

DIESEL ENGINE	GASOLINE ENGINE
Intake of air	Intake of fuel and air
Compression of air . . .	Compression of fuel-air mixture
Injection of fuel	
Ignition and combustion of charge	Ignition and combustion of charge
Expansion of gases . . .	Expansion of gases
Removal of waste	Removal of waste

In the process of engine operation, beginning with the admission of air and fuel and following through to the removal of the expanded gases, a series of events or phases take place. The term "cycle" identifies the sequence of events that takes place in the cylinder of an engine for each power impulse transmitted to the crankshaft. These events always occur in the same order each time the cycle is repeated. The number of events occurring in a cycle of operation depends upon whether the engine is diesel or gasoline. Table 2-1 shows the events and their sequence in one cycle of operation of each of these types of engines.

The principal difference, as shown in the table, in the cycles of operation for diesel and gasoline engines involves the admission of fuel and air to the cylinder. While this takes place as one event in a gasoline engine, it involves two events in a diesel engine. Thus, insofar as events are concerned, there are six main events taking place in the diesel engine's cycle of operation and five in the gasoline engine's cycle. We emphasize the number of events which take place because they are not identical to the number of piston strokes which occur during a cycle of operation. Even though the events of a cycle are closely related to piston position and movement, ALL of the events will take place during a cycle regardless of the number of piston strokes involved. We shall discuss the relationship of events and piston strokes later in this chapter.

From the preceding discussion, it is apparent that a cycle of operation in either a diesel or gasoline engine involves two basic factors–heat and mechanics. Any explanation of the relationship of heat to the motion of the engine parts–that is, the means by which heat energy is transformed into mechanical energy–involves many terms such as matter, molecule, energy, heat, temperature, the mechanical equivalent of heat, force, pressure, volume, work, and power. (If you need to review these terms, see the appropriate sections in *Fireman*, NAVEDTRA 10520-E and *Basic Machines*, NAVPERS 10624-A.)

The mechanics of engine operation is referred to as the MECHANICAL, or operating, CYCLE of an engine, while the heat process which produces the forces that move engine parts is referred to as the COMBUSTION CYCLE. A cycle of each type is included in a cycle of engine operation.

MECHANICAL CYCLES

We have talked about the events taking place in a cycle of engine operation but have said nothing about piston strokes except that a complete sequence of events will occur during a cycle regardless of the number of strokes made by the piston. The number of piston strokes occurring during any one cycle of events is limited to either two or four, depending on the design of the engine. Thus, we have a 4-stroke cycle and a 2-stroke cycle. These cycles are known as the mechanical cycles of operation.

From your study of *Fireman*, NAVEDTRA 10520-E, you will recall that the terms "4-stroke" and "2-stroke" identify the number of strokes the piston makes during a cycle of events; also, that both types of mechanical cycles are used in both types of reciprocating engines. However, most gasoline engines in Navy service operate on the 4-stroke cycle, and a greater number of diesels operate on the 2-stroke than on the 4-stroke cycle. Since you may be required to operate and maintain engines operating on either of the mechanical cycles, you should be familiar with the principal differences in these cycles. The relationship between the events and piston strokes occurring in a cycle of operation involves some of these differences. A thorough understanding of the relationship will aid you in carrying out your duties in connection with engine operation and maintenance.

Relationship of Events and Strokes in a Cycle

A piston stroke is the distance a piston moves between limits of travel. The cycle of operation in an engine operating on the 4-stroke cycle involves four piston strokes–INTAKE, COMPRESSION, POWER, and EXHAUST. In the 2-stroke cycle, only two strokes are involved–POWER and COMPRESSION.

In figure 2-1 (foldout at the end of this chapter), the strokes are named to correspond to the events. However, since six events are listed for diesel engines, it is evident that more than one event takes place during some of the strokes, especially in the 2-stroke cycle. Even so, it is common practice to identify some of the events as strokes of the piston because such events as intake, compression, power, and exhaust in a 4-stroke cycle involve at least a major portion of a stroke and, in some cases, more than one stroke. The same is true of power and compression events and strokes in a 2-stroke cycle. Such association of events and strokes overlooks other events taking place during a cycle of operation. The oversight sometimes

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leads to confusion when one studies the operation of an engine or deals with maintenance problems involving the timing of ignition systems of fuel injection systems.

4-Stroke Cycle Diesel Engine

To help you understand the relationship between events and strokes we shall discuss the number of events that occur during a specific stroke, the duration of an event with respect to a piston stroke, and the cases where one event overlaps another. The relationship of events to strokes can be demonstrated best by showing the changing situation in a cylinder during a cycle of operation. Figure 2-1 illustrates these changes for a 4-stroke cycle diesel engine.

The relationship of events to strokes is more readily understood, if the movements of a piston and its crankshaft are considered first. Figure 2-1A shows the reciprocating motion and stroke of a piston and the rotary motion of the crank during two piston strokes. The positions of the piston and crank at the start and end of a stroke are marked "top" and "bottom," respectively.

If these positions and movements are marked on a circle (fig. 2-1B), the piston position, when at the top of a stroke, is located at the top of the circle. When the piston is at the bottom of a stroke, the piston position is located at the bottom center of the circle.

Note in parts A and B of figure 2-1 that top center and bottom center identify points where changes in direction of motion take place. In other words, when the piston is at top center, upward motion has stopped and downward motion is ready to start or, with respect to motion, the piston is "dead." The points which designate changes in direction of motion for a piston and crank are frequently called TOP DEAD CENTER (TDC) and BOTTOM DEAD CENTER (BDC).

The circle illustrated in part B of figure 2-1 is broken at various points and "spread out" to create part C of the figure. In studying figure 2-1C, you should keep TDC and BDC in mind since they identify the start and end of a STROKE and since they are the points from which the start and end of EVENTS are established.

By following the strokes and events as illustrated, you can see that the intake event starts before TDC, or before the actual down stroke (intake) starts, and continues on past BDC, or beyond the end of the stroke. The compression event starts when the intake event ends, but the upstroke (compression) has been in process since BDC. The injection and ignition events overlap with the latter part of the compression event, which ends at TDC. The burning of the fuel continues a few degrees past TDC. The power event or expansion of gases ends several degrees before the down (power) stroke ends at BDC. The exhaust event starts when the power event ends and continues through the complete upstroke (exhaust) and past TDC. Note the overlap of the exhaust event with the intake event of the next cycle. The details on why certain events overlap and why some events are shorter or longer with respect to strokes will be given later in this manual.

From the preceding discussion, you should understand why the term "stroke" is sometimes used to identify an event which occurs in a cycle of operation. However, it is best to keep in mind that a stroke involves 180° of crankshaft rotation (or piston movement between dead centers), while the corresponding event may take place during a greater or lesser number of degrees of shaft rotation.

2-Stroke Cycle Diesel Engine

The relationship of events to strokes in a 2-stroke cycle diesel engine is shown in figure 2-2 (foldout at the end of this chapter). Comparison of figures 2-1 and 2-2 reveals a number of differences between the two types of mechanical or operating cycles. These differences are not too difficult to understand if you remember that four piston strokes and 720° (180° per stroke) of crankshaft rotation are involved in the 4-stroke cycle, while only half as many strokes and degrees are involved in a 2-stroke cycle. One special requirement of 2-stroke cycle engines is that the air charge for the cylinder must be forced into the cylinder in some way. A 4-stroke cycle engine can be charged by atmospheric pressure, but the incoming air to a 4-stroke cycle engine must displace the combustion gases which remain in the cylinder. Small 2-stroke cycle gasoline engines use pressure developed in the crankcase by the descending piston to force air into the cylinder. Diesel engines use an external blower or supercharger to perform this function. The incoming air replaces or scavenges the combustion gases from the cylinder. Reference to the cross-sectional illustrations (the five inserts in fig. 2-2) will help you to associate the event with the relative position of the piston. Even though the two piston strokes are frequently referred to as power and compression, they are identified as the "down stroke" (TDC to BDC) and "up stroke" (BDC to TDC) in this discussion in order to avoid confusion when reference is made to an event.

Starting with the admission of air, or scavenging event, (1) in the circle in figure 2-2, the piston is in the lower half of the down stroke and the exhaust event (6) is in process. The exhaust event started a number of degrees before scavenging, both (exhaust and scavenging) starting several degrees before the piston reached BDC. The overlap of these events permits the incoming air (1) to clear the cylinder of exhaust gases. Note that the exhaust event stops a few degrees before the intake event stops, but several degrees after the upstroke of the piston has started. (The exhaust event in some other 2-stroke cycle diesel engines ends a few degrees after the intake event ends.) When the scavenging event ends, the cylinder is charged with the air which is to be compressed. The compression event (2) takes place during the major portion of the upstroke.

The injection event and ignition (3) and combustion (4) occur during the latter part of the upstroke. (The point at which injection ends varies with engines. In some engines, it ends before TDC; in others, a few degrees after TDC.) The intense heat generated during the compression of the air ignites the fuel-air mixture and the pressure resulting from combustion forces the piston down.

The expansion (5) of the gases continues through a major portion of the down stroke. After the force of the gases has been expended, the exhaust valve opens (6) and permits the burned gases to enter the exhaust manifold. As the piston moves downward, the intake ports are uncovered (1) and the incoming air clears the cylinder of the remaining exhaust gases and fills the cylinder with a fresh air charge (1); thus, the cycle of operation has started again.

Now, what is the difference between the 2- and 4-stroke cycles? From the standpoint of the mechanics of operation, the principal difference is the number of piston strokes taking place during the cycle of events. A more significant difference is that a 2-stroke cycle engine delivers twice as many power impulses to the crankshaft for every 720° of shaft rotation. (See fig. 2-3.)

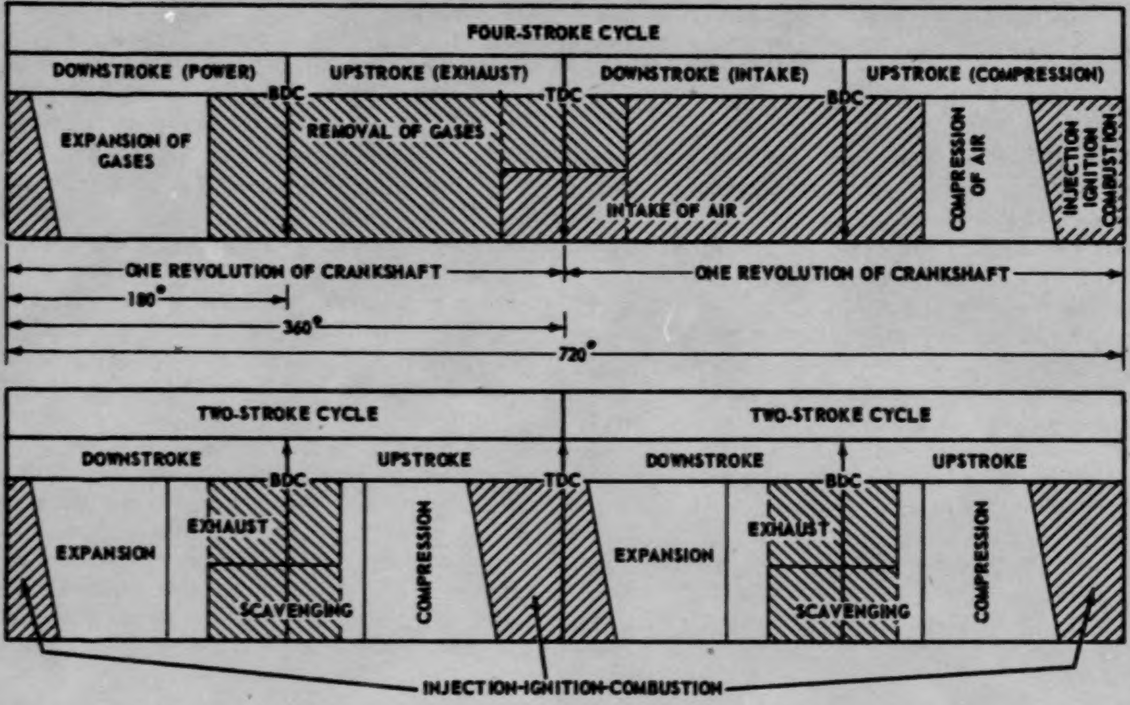
The illustrations we have used to represent the cycles of operation are for demonstration purposes only. The exact number of degrees before or after TDC or BDC at which an event starts and ends will vary among engines. You can find information on such details in the appropriate technical manuals dealing with the specific engine in question.

Gasoline Engines

Diagrams showing the mechanical cycles of operation in gasoline engines would be somewhat similar to those described for diesel engines, except that there would be one less event taking place during the gasoline engine cycle. Since air and fuel are admitted to the cylinder of a gasoline engine as a mixture during the intake event, the injection event does not apply.

COMBUSTION CYCLES

To this point, we have given greater consideration to the stroke of a piston and the


FOUR-STROKE CYCLE
DOWNSTROKE (POWER)
UPSTROKE (EXHAUST)
DOWNSTROKE (INTAKE)
UPSTROKE (COMPRESSION)
BDC
TDC
BDC
EXPANSION OF GASES
REMOVAL OF GASES
INTAKE OF AIR
COMPRESSION OF AIR
INJECTION IGNITION COMBUSTION
ONE REVOLUTION OF CRANKSHAFT
ONE REVOLUTION OF CRANKSHAFT
180°
360°
720°
TWO-STROKE CYCLE
TWO-STROKE CYCLE
DOWNSTROKE
UPSTROKE
DOWNSTROKE
UPSTROKE
BDC
TDC
BDC
EXPANSION
EXHAUST
SCAVENGING
COMPRESSION
EXPANSION
EXHAUST
SCAVENGING
COMPRESSION
INJECTION-IGNITION-COMBUSTION

54.19.20

Figure 2-3.—Comparison of the 2- and 4-stroke cycles.

related events taking place during a cycle of operation than we have to the heat process involved in the cycle. However, the mechanics of engine operation cannot be discussed without dealing with heat. Such terms as ignition, combustion, and expansion of gases indicate that heat is essential to a cycle of engine operation. So far, the only difference we have pointed out between diesel and gasoline engines is in the number of events occurring during the cycle of operation. We have told you that either the 2- or the 4-stroke cycle may apply to both a diesel and a gasoline engine. Then, one of the principal differences between these types of engines must involve the heat process used to produce the forces which make the engine operate. The heat processes are sometimes called combustion or heat cycles.

The two most common combustion cycles associated with reciprocating internal-combustion engines are the OTTO cycle (gasoline engines) and the DIESEL cycle (diesel engines).

In talking about combustion cycles, we bring up another important difference between gasoline and diesel engines—COMPRESSION PRESSURE, which is directly related to the combustion process in an engine. Diesel engines have a much higher compression pressure than gasoline engines. The higher compression pressure in diesels explains the difference in the methods of ignition used in gasoline and diesel engines.

Methods of Ignition

When the gases within a cylinder are compressed, the temperature of the confined gases rises; the greater the compression, the higher the temperature. In a gasoline engine, the compression temperature is always lower than the point at which the fuel will ignite spontaneously. Thus, the heat required to ignite the fuel must come from an external source—SPARK IGNITION. On the other hand, the compression temperature in a diesel engine is far above the ignition point of the fuel oil; therefore, ignition takes place as a result of heat generated by compression of the air within the cylinder—COMPRESSION IGNITION.

The difference in the methods of ignition indicates that there is a basic difference in the combustion cycles upon which diesel and gasoline engines operate. The difference involves the behavior of the combustion gases under varying conditions of pressure, temperature, and volume. Since this is so, you should be familiar with the relationship of these factors before considering the combustion cycles individually. (The basic laws and processes involved in a volume, temperature, and pressure relationship are discussed under the properties of gases in *Fireman*, NAVEDTRA 10520-E.)

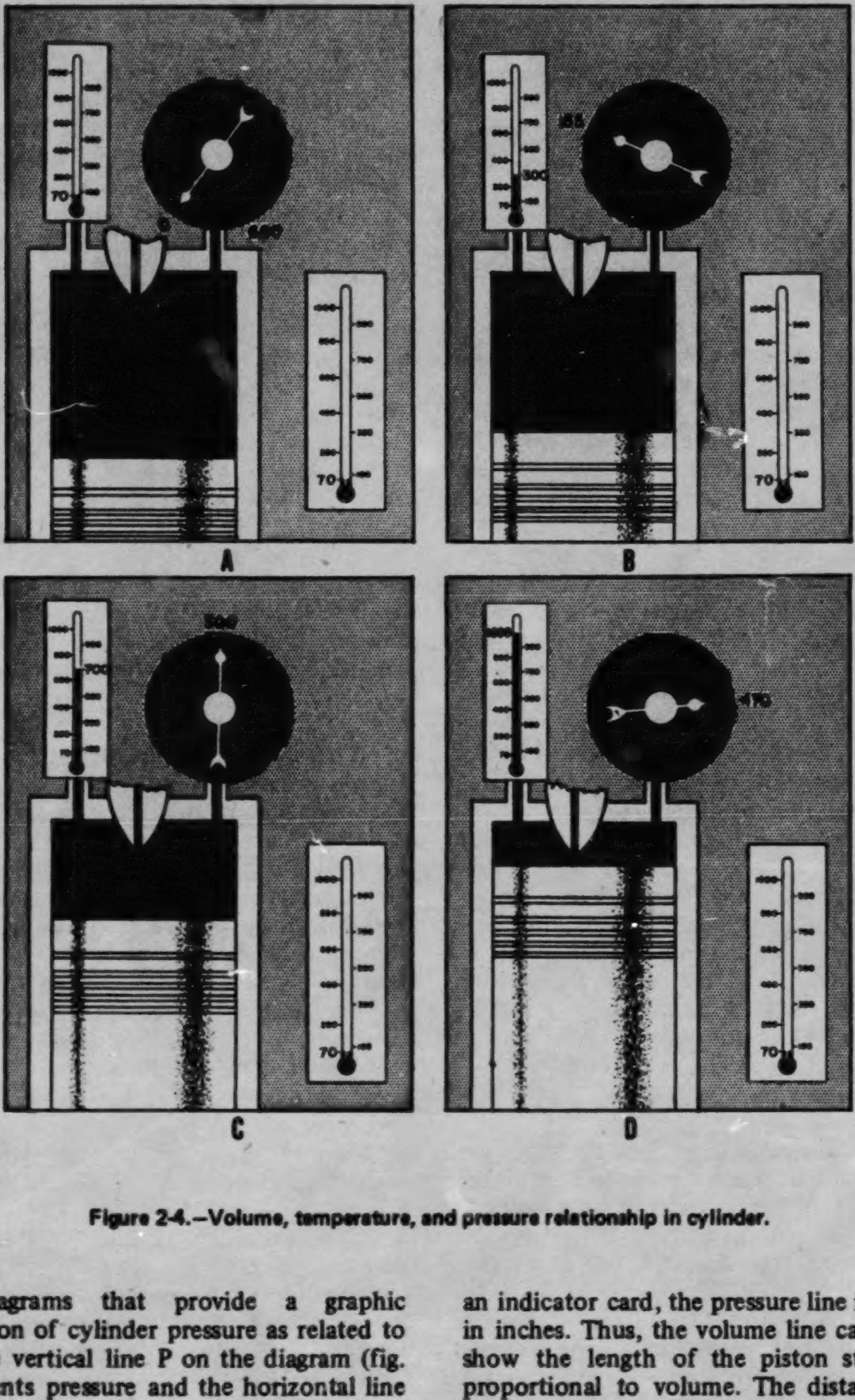
RELATIONSHIP OF TEMPERATURE, PRESSURE, AND VOLUME.—The relationship of temperature, pressure, and volume as found in an engine can be illustrated by describing what takes place in a cylinder fitted with a reciprocating piston. Follow figure 2-4 (parts A through D) as we demonstrate. Note the instruments that indicate the pressure within the cylinder and the temperature both inside and outside the cylinder. In part A the air in the cylinder is at atmospheric pressure and the temperatures, inside and outside the cylinder, are approximately 70° F.

When the cylinder is an airtight container, as it is in our example, if a force pushes the piston toward the top of the cylinder, the entrapped charge is compressed. In parts B and C, as the compression progresses, the VOLUME of the air DECREASES, the PRESSURE INCREASES, and the TEMPERATURE RISES. These changing conditions continue as the piston moves. When the piston nears TDC in part D, there has been a marked decrease in volume, and both pressure and temperature are much greater than at the beginning of compression. Note that pressure has gone from 0 to 470 psi and temperature has increased from 70° F to approximately 1,000° F. These changing conditions indicate that mechanical energy, in the form of force applied to the piston, has been transformed into heat energy in the compressed air. The temperature of the air has been raised sufficiently to cause ignition of fuel injected into the cylinder.

Further changes take place after ignition. Since ignition occurs shortly before TDC, there is little change in volume until the piston passes TDC. However, there is a sharp increase in both pressure and temperature shortly after ignition takes place. The increased pressure forces the piston downward. As the piston moves downward, the gases expand (increase in volume), and pressure and temperature decrease rapidly. The changes in volume, pressure, and temperature, which we have just described and illustrated, are representative of the changing conditions in the cylinder of a modern diesel engine.

A gasoline engine, on the other hand, needs a lower compression ratio and lower combustion chamber temperatures. The reason for this is that the heat of compression of a diesel engine would ignite a gasoline and air mixture before the piston came near the top of its stroke. This pre-ignition would tend to drive the piston back down the bore and place an excessive and damaging strain on the engine. As a rule, gasoline engines use compression ratios under 10:1, and it is the electric spark from the plug that causes combustion to occur at the proper time.

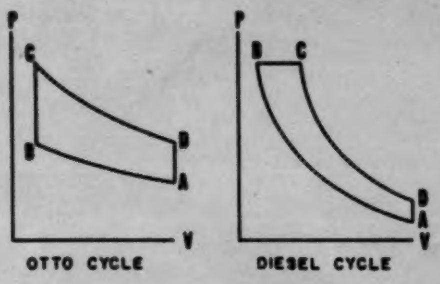
The changes in volume and pressure in an engine cylinder can be illustrated by diagrams similar to those shown in figure 2-5. Such diagrams are made by devices which measure and record the pressures at various piston positions during a cycle of engine operation. Diagrams that show the relationship between pressures and corresponding piston positions are called PRESSURE-VOLUME DIAGRAMS or INDICATOR CARDS.



75.4

Figure 2-4.—Volume, temperature, and pressure relationship in cylinder.

On diagrams that provide a graphic representation of cylinder pressure as related to volume, the vertical line P on the diagram (fig. 2-5) represents pressure and the horizontal line V represents volume. When a diagram is used as an indicator card, the pressure line is marked off in inches. Thus, the volume line can be used to show the length of the piston stroke that is proportional to volume. The distance between adjacent letters on each of the diagrams (fig.



75.5

Figure 2-5.—Pressure-volume diagrams for theoretical combustion cycles.

2-5) represents an event of a combustion cycle—that is, compression of air, burning of the charge, expansion of gases, and removal of gases.

The diagrams shown in figure 2-5 provide a means by which the otto and diesel combustion cycles can be compared. Referring to the diagrams while studying the following discussion of these combustion cycles will help you identify the principal differences between the cycles. The diagrams shown are theoretical pressure-volume diagrams. Diagrams representing conditions in operating engines are given later.

Otto (Constant-Volume) Cycle

In theory, the otto combustion cycle is one in which combustion, induced by spark ignition, occurs at constant volume. The otto cycle and its principles serve as the basis for modern gasoline engine design.

In the otto cycle (fig. 2-5) compression of the charge in the cylinder occurs at line AB. Spark ignition occurs at B, and, due to the volatility of the mixture, combustion practically amounts to an explosion. Combustion, represented by line BC, occurs (theoretically) just as the piston reaches TDC. During combustion, there is no piston travel; thus, there is no change in the volume of the gas in the cylinder. This accounts for the descriptive term, CONSTANT VOLUME. During combustion, there is a rapid rise in temperature followed by a pressure increase which performs the work during the expansion phase, represented by line CD. The removal of gases, represented by line DA, is at constant volume.

Theoretical Diesel (Constant-Pressure) Cycle

When discussing diesel engines, we must point out that there is a difference between the theoretical, or "true," diesel cycle and the "actual" diesel cycle, which really occurs in an operating diesel engine.

The true diesel cycle may be defined as one in which combustion, induced by compression ignition, theoretically occurs at a constant pressure. (See fig. 2-5.) Compression (line AB) of the air increases its temperature to a point that ignition occurs automatically when the fuel is injected. Fuel injection and combustion are controlled to give constant-pressure combustion (line BC). This is followed by expansion (line CD) and constant-volume rejection of the gases (line DA.)

In the true diesel cycle, the burning of the mixture of fuel and compressed air is a relatively slow process when compared with the quick, explosive-type combustion process of the otto cycle. The injected fuel penetrates the compressed air, some of the fuel ignites, then the rest of the charge burns. The expansion of the gases keeps pace with the change in volume caused by piston travel; thus combustion is said to occur at CONSTANT PRESSURE (line BC).

Actual Combustion Cycles

The preceding discussion covered the theoretical (true) combustion cycles which serve as the basis for modern engines. In actual operation, modern engines operate on modifications of the theoretical cycles. However, some characteristics of the true cycles are incorporated in the actual cycles of modern engines, as you will see in the following discussion of examples representing the actual cycles of operation in gasoline and diesel engines.

The examples we will use are based on the 4-stroke mechanical cycle (the majority of gasoline engines use this type cycle) so that you may compare the cycles found in both gasoline and diesel engines. We will also point out differences existing in diesel engines operating on the 2-stroke cycle.

The diagrams in figures 2-6 and 2-7 are representative of the changing conditions in a cylinder during engine operation. Some of the events are exaggerated to show more clearly the change that takes place and, at the same time, to show how the theoretical and actual cycles differ.

The compression ratio situation and a pressure-volume diagram for a 4-stroke otto cycle are shown in figure 2-6. Part A shows the piston on BDC at the start of an upstroke. (In a 4-stroke cycle engine, this stroke could be either that identified as the compression stroke or the exhaust stroke.) Notice that in moving from BDC to TDC (part B) the piston travels 5/6 of the total distance ab. In other words, the VOLUME has been decreased to 1/6 of the volume when the piston was at BDC. Thus, the compression ratio is 6 to 1.

Part C shows the changes in volume and pressure during one complete 4-stroke cycle. Note that the lines representing the combustion and exhaust phases are not straight as they were in the theoretical diagram. As in the diagram of the theoretical cycle, the vertical line at the left represents cylinder pressure in psi. Atmospheric pressure is represented by a horizontal line called the ATMOSPHERIC PRESSURE LINE. Pressures below this line are less than atmospheric pressures, while pressures above the line are more than atmospheric. The bottom horizontal line represents cylinder volume and piston movement. The volume line is divided into six parts which correspond to the divisions of volume shown in part A. Since piston movement and volume are proportional, the distance between 0 and 6 indicates the volume when the piston is at BDC, and the distance from 0 to 1 indicates the volume with the piston at TDC. Thus, the distance from 1 to 6 corresponds to total piston travel with the numbers in between identifying changes in volume which result from the reciprocating motion of the piston. The curved lines of part C (fig. 2-6) represent the changes of both pressure and volume which take place during the four piston strokes of the cycle.

To make it easier for you to compare the discussion on the relationship of strokes and events in the diesel 4-stroke cycle (fig. 2-1) with the discussion on the otto 4-stroke cycle (fig. 2-6), we will begin the cycle of operation at the intake. In the otto cycle, the intake event includes the admission of fuel and air. As indicated earlier, the intake event starts before TDC, or at point a in part C of figure 2-6. Note that pressure is decreasing and that after the piston reaches TDC and starts down, a vacuum is created which facilitates the flow of the fuel-air mixture into the cylinder. The intake event continues a few degrees past BDC ending at point b. Since the piston is now on an upstroke, compression takes place and continues until the piston reaches TDC. Note the increase in pressure (X to X′) and the decrease in volume (f to X). Spark ignition at c starts combustion which takes place very rapidly. There is some change in volume since the phase starts before TDC and ends after TDC.

Pressure increases sharply during the combustion phase (curve cd). The increase in pressure provides the force necessary to drive the piston down again. The gases continue to expand as the piston moves toward BDC, and the pressure decreases as the volume increases, from d to e. The exhaust event starts at e, a few degrees before BDC, and the pressure drops rapidly until the piston reaches BDC. As the piston moves toward TDC, there is a slight drop in pressure as the waste gases are discharged. The exhaust event continues a few degrees past TDC to point g so that the incoming charge aids in removing the remaining waste gases.

The ACTUAL DIESEL COMBUSTION CYCLE is one in which the combustion phase, induced by compression ignition, begins on a constant-volume basis and ends on a constant-pressure basis. In other words, the actual cycle is a combination of features found

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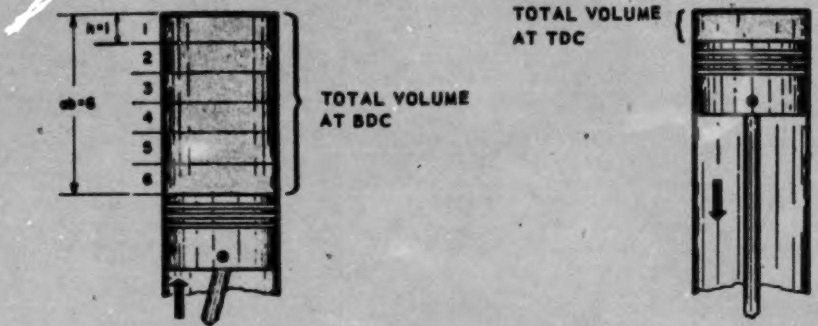
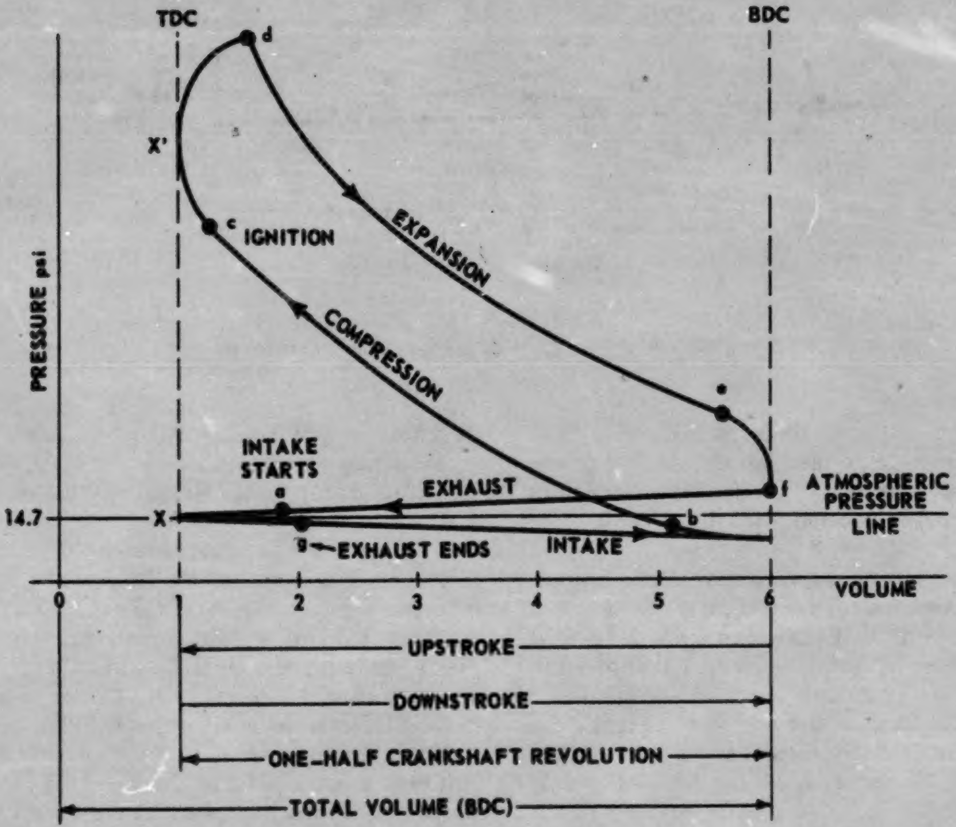

a=1
1
2
3
4
5
6
ab=6
TOTAL VOLUME AT BDC
TOTAL VOLUME AT TDC

A - START OF UPSTROKE (COMPRESSION OR EXHAUST)

B - START OF DOWNSTROKE (POWER OR INTAKE)

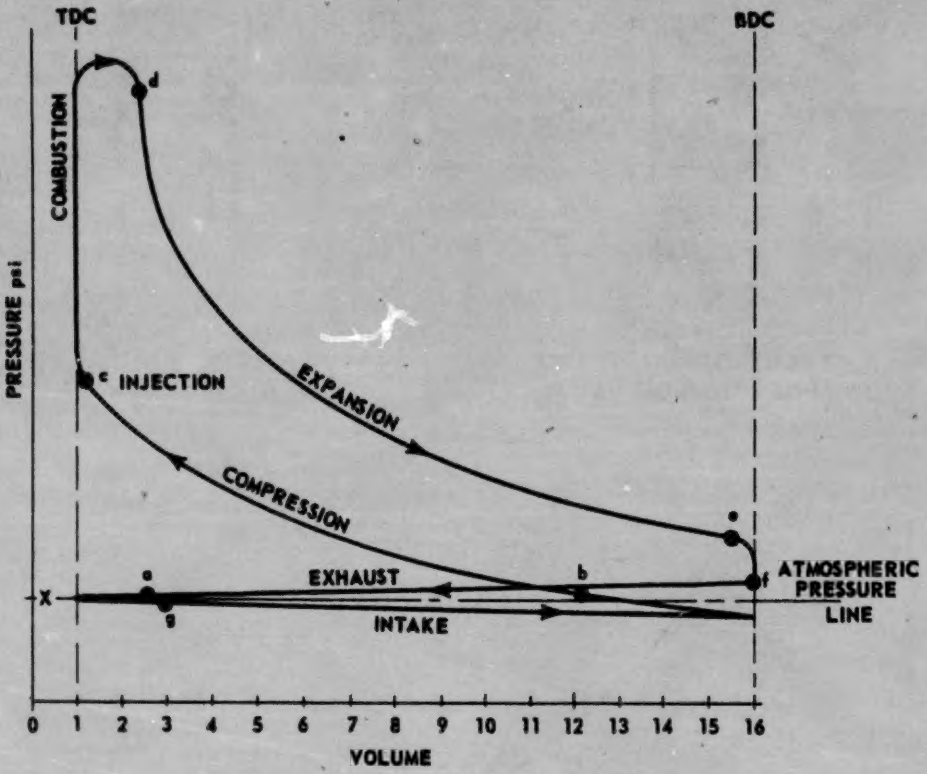


C - CYCLE DIAGRAM

54.19B

Figure 2-6.—Pressure-volume diagram, otto 4-stroke cycle.

32



54.19C

Figure 2-7.—Pressure-volume diagram, diesel 4-stroke cycle.

in both the otto and theoretical diesel cycles. The actual cycle is used as the basis for the design of practically all modern diesel engines and is referred to as a modified diesel cycle.

An example of a pressure-volume diagram for a modified 4-stroke diesel engine is shown in figure 2-7. Note that the volume line is divided into 16 units, indicating a 16 to 1 compression ratio. The higher compression ratio accounts for the increased temperature necessary to ignite the charge. Fuel is injected at point c and combustion is represented by line cd. While combustion in the otto cycle is at constant-volume practically throughout the phase, combustion in the actual diesel cycle takes place with volume practically constant for a short time, during which period there is a sharp increase in pressure, until the piston reaches a point slightly past TDC. Then, combustion continues at a relatively constant pressure, dropping lightly as combustion ends at d.

Pressure-volume diagrams for gasoline and diesel engines operating on the 2-stroke cycle are similar to those just discussed, except that separate exhaust and intake curves do not exist. They do not exist because intake and exhaust occur during a relatively short interval of time near BDC and do not involve full strokes of the piston as in the 4-stroke cycle. Thus, a pressure-volume diagram for a 2-stroke modified diesel cycle will be similar to a diagram formed by f-b-c-d-e-f in figure 2-7. The exhaust and intake phases will take place between e and b with some overlap of the events. (See fig. 2-2.)

The preceding discussion has pointed out some of the main differences between engines that operate on the otto cycle and those that operate on the diesel cycle. In brief, these differences involve (1) the mixing of fuel and air, (2) compression ratio, (3) ignition, and (4) the combustion process.

In mentioning differences in engines, there is another variation you may find in the engines you operate and maintain; sometimes, the manner in which the pressure of combustion gases acts upon the piston is used as a method of classifying engines.

ENGINES CLASSIFIED ACCORDING TO THE ACTION OF PRESSURE ON PISTONS

Engines are classified in many ways. You are already familiar with some classifications such as those based on (1) fuels used (diesel fuel and gasoline), (2) the ignition methods (spark and compression), (3) the combustion cycles (otto and diesel), and (4) the mechanical cycles (2-stroke and 4-stroke). Additional information is given in subsequent chapters of this manual on some of the factors related to the above classifications as well as to other classifications, such as those based on the cylinder arrangements (V, in-line, opposed, etc), the cooling media (liquid and air), and the valve arrangements) (L-head, valve-in head, etc).

Classification of engines according to combustion-gas action is based on whether the pressure created by the combustion gases acts upon one or two surfaces of a single piston or against single surfaces of two separate and opposed pistons. The two types of engines under this classification are commonly referred to as single-acting and opposed-piston engines. The opposed-piston engine is actually a form of single-acting engines since pressure is applied to only one surface of the pistons. True double-acting diesel engines have been built, but they are no longer in use.

SINGLE-ACTING ENGINES

Engines of the single-acting type have one piston per cylinder with the pressure of combustion gases acting on only one surface of the piston. This is a feature of design rather than principle, because the basic principles of operation apply whether an engine is single acting or opposed piston.

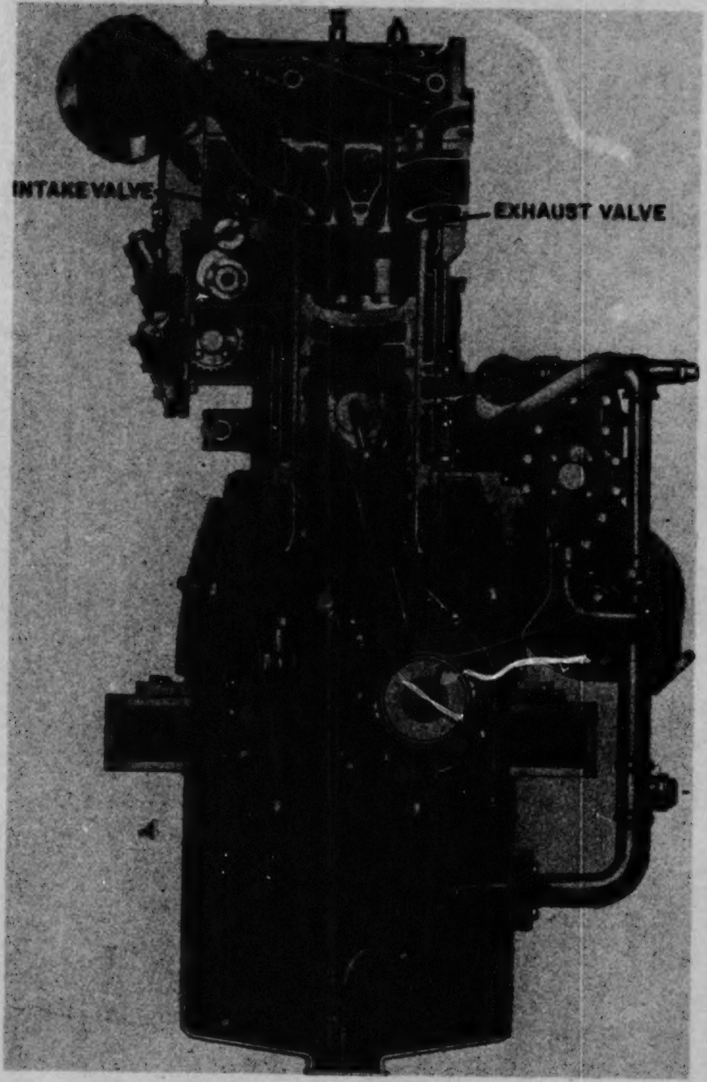
The pistons in most single-acting diesel engines are of the trunk type (length greater than diameter). The barrel or wall of a piston of this type has one end closed (crown) and one end open (skirt end). Only the crown of a trunk piston serves as part of the combustion space surface. Therefore, the pressure of combustion can act only against the crown; thus, with respect to the surfaces of a piston, pressure is single acting.

Most reciprocating internal-combustion engines are of the single-acting type. All 4-stroke cycle engines (fig. 2-8) and most 2-stroke cycle engines (fig. 2-9) are single acting. Since this is true, you will find that most modern gasoline engines, as well as most of the diesel engines used by the Navy, are single acting.

With respect to the combustion-gas action, the term opposed-piston identifies those engines which have TWO PISTONS and ONE COMBUSTION SPACE in each cylinder. The pistons are arranged in "opposed" positions; that is, crown to crown, with the combustion space in between. (See fig. 2-10.) When combustion takes place, the gases act against the crowns of both pistons, driving them in opposite directions. Thus, the term "opposed" not only signifies that, with respect to pressure and piston surfaces, the gases act in "opposite" directions, but also classifies piston arrangement within the cylinder.

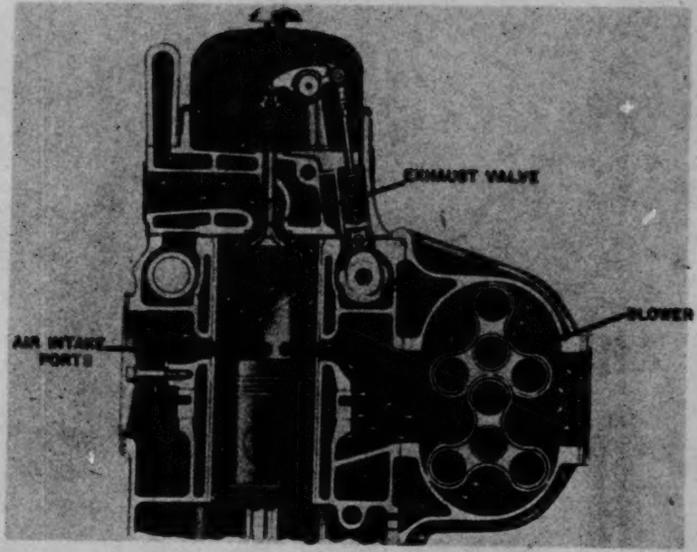
(NOTE: Engines of the opposed-piston type are not to be confused with engines of the "flat" or 180° V-type. Flat engines have two rows of cylinders in a horizontal plane with one crankshaft located between the rows and serving both rows of cylinders. Engines of this design are of single-acting type and are sometimes referred to as horizontal-opposed engines (the term is based on cylinder arrangement.)

In modern engines that have the opposed-piston arrangement, two crankshafts


INTAKE VALVE
EXHAUST VALVE

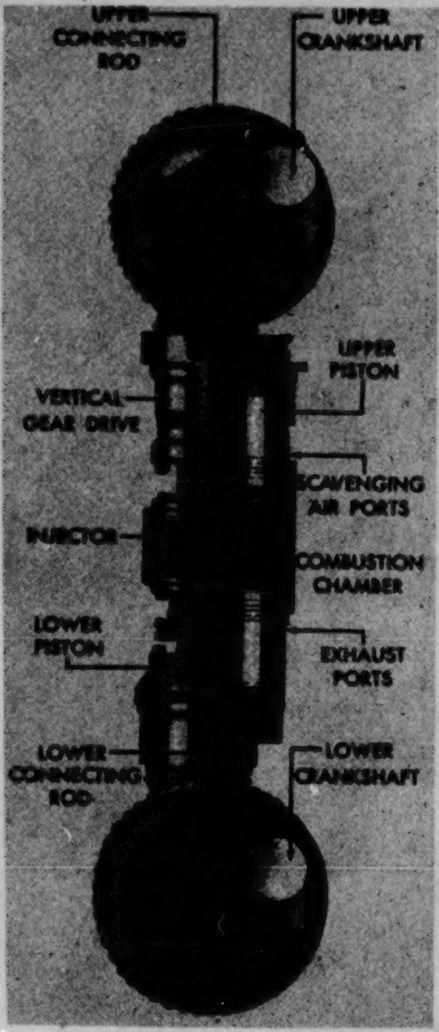
75.114

Figure 2-8.—4-stroke diesel engine (Cooper-Bessemer).


EXHAUST VALVE
BLOWER
AIR INTAKE PORTS

75.151

Figure 2-9.—2-stroke cycle diesel engine (GM-71 series).



75.8
Figure 2-10.–Cylinder and related parts–opposed-piston engine.

(upper and lower) are required for transmission of power. Both shafts contribute to the power output of the engine. In most opposed-piston engines common to Navy service, the crankshafts are connected by a vertical drive. (See fig. 2-10.)

The cylinders of opposed-piston engines have scavenging air ports located near the top. These ports are opened and closed by the upper piston. Exhaust ports located near the bottom of the cylinder are closed and opened by the lower piston.

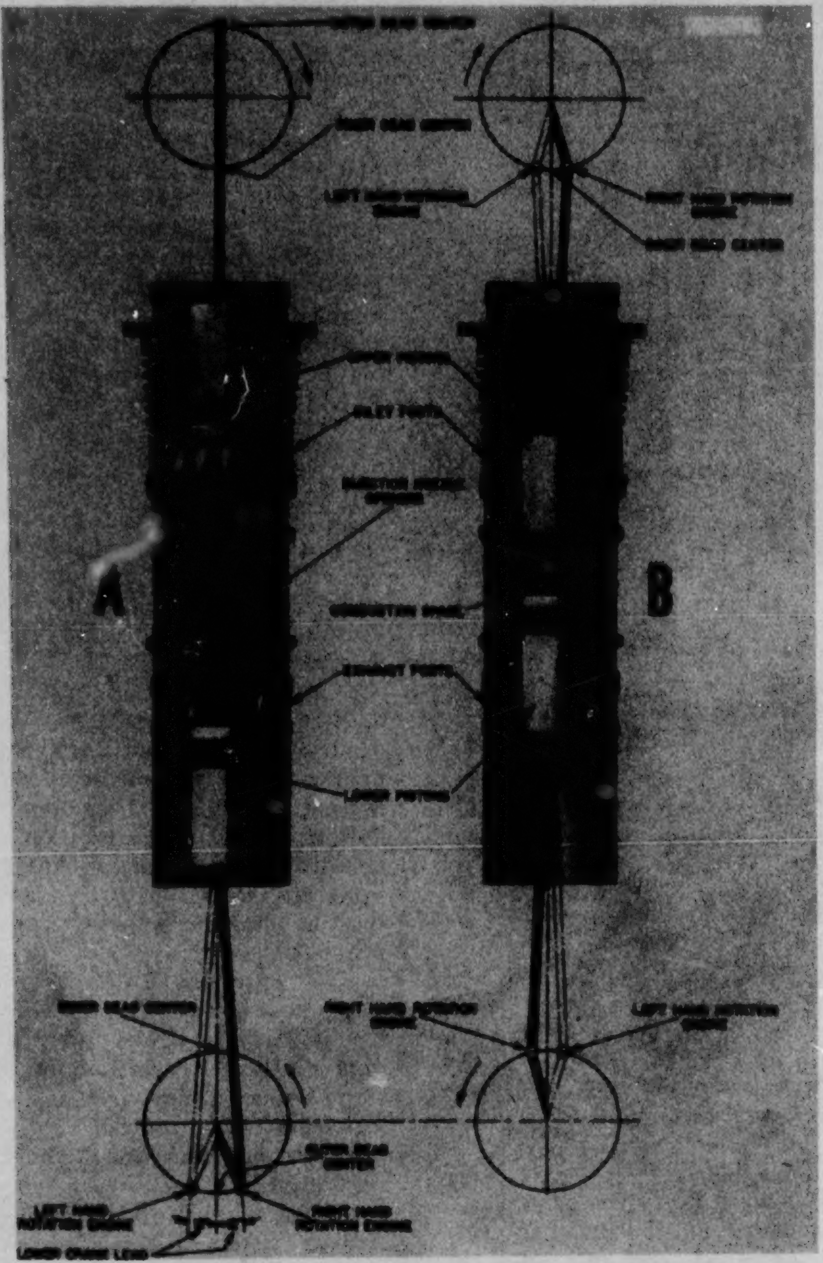
Movement of the opposed pistons is such that the crowns are closest together near the center of the cylinder. When at this position, the pistons are not at the true piston dead centers. This is because the lower crankshaft operates a few degrees in advance of the upper shaft. The number of degrees that a crank on the lower shaft travels in advance of a corresponding crank on the upper shaft is called LOWER CRANK LEAD. (See fig. 2-11.)

Note in part A of figure 2-11 that the lower crankshaft is 12° PAST outer dead center (ODC) while the upper piston in ON outer dead center. In other words, the lower shaft leads the upper shaft by 12° of rotation. (Outer dead center and inner dead center (IDC) correspond, respectively, to BDC and TDC of single-acting engines.)

In part B, the lower shaft is shown a few degrees PAST IDC and the upper shaft the same number of degrees BEFORE IDC. (Keep in mind that the shafts rotate in opposite directions.) With the shafts at these positions, the pistons are closest together and are sometimes referred to as being at COMBUSTION DEAD CENTER. Note that the midpoint between the shaft positions is piston dead center.

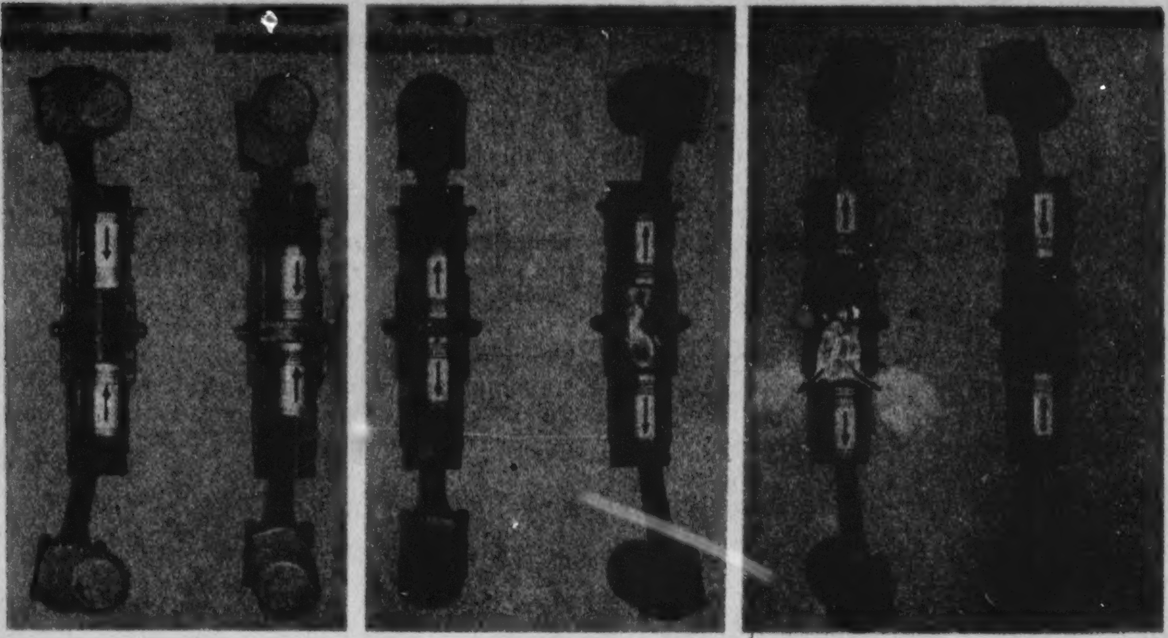
Opposed-piston engines used by the Navy operate on the 2-stroke cycle. In engines of the opposed-piston type, as in 2-stroke cycle single-acting engines, there is an overlap of the various events occurring during a cycle of operation. Injection and the burning of the fuel start during the latter part of the compression event and extend into the power phase. There is also an overlap of the exhaust and scavenging periods. The events in the cycle of operation of an opposed-piston, 2-stroke diesel cycle engine are shown in figure 2-12.

In figure 2-12 (1), the cylinder is charged with air and the pistons are moving toward IDC. Since the scavenging air ports are covered by the


OUTER DEAD CENTER
INNER DEAD CENTER
LEFT HAND ROTATION ENGINE
RIGHT HAND ROTATION ENGINE
INNER DEAD CENTER
UPPER PISTONS
INLET PORTS
INJECTION NOZZLE OPENING
A
COMBUSTION SPACE
B
EXHAUST PORTS
LOWER PISTONS
INNER DEAD CENTER
RIGHT HAND ROTATION ENGINE
LEFT HAND ROTATION ENGINE
OUTER DEAD CENTER
LEFT HAND ROTATION ENGINE
RIGHT HAND ROTATION ENGINE
LOWER CRANK LEAD

75.9X

Figure 2-11.—Lower crank lead, opposed-piston engine.



75.10

Figure 2-12.–Events in operating cycle of an opposed-piston engine.

upper piston and the exhaust ports are covered by the lower piston, compression is taking place. A few degrees before the lower piston reaches IDC, fuel is injected (2) and combustion occurs. Injection is completed (3) slightly before the pistons reach combustion dead center, where compression is highest. The combustion of the fuel almost doubles the pressure shortly after this point in the cycle. As the gases expand (4), the pistons are driven in opposite directions toward the outer dead centers and power is transmitted to both crankshafts. As the pistons approach ODC, the lower piston uncovers the exhaust ports and most of the waste gases escape. This is followed by the upper piston uncovering the scavenging air ports (5). The scavenging air forces the remaining gases out of the cylinder. Then, the lower piston covers the exhaust ports (6) and air continues to fill the cylinder until the upper piston covers the scavenging air ports, thus completing the cycle.

In the cycle of operation just described, the exhaust ports are uncovered (5) and covered (6) slightly before the intake ports are opened and closed because of the lower crankshaft lead. Lower crank lead influences scavenging as well as power output.

Since the intake ports are open for a brief interval after the exhaust ports close, air can be forced into the cylinder at a pressure above that of the atmosphere (i.e., the cylinder can be supercharged). This results in the development of more power than would be possible if pressure were normal.

Crank lead also results in less power being delivered to the upper shaft than to the lower shaft. The amount of power transmitted to each crankshaft differs because, by the time the upper piston reaches IDC after injection and combustion, the lower piston has already entered the power phase of the cycle. The lower piston, therefore, receives the greater part of the force created by combustion. In other words, by the time the upper piston reaches IDC and begins to transmit power, the volume of the gases has already begun to increase. Therefore, the pressure acting on the upper piston is less than that acting on the lower piston when it began to deliver power.

The power delivered by the lower crankshaft varies with engine models. In some engines, from 70% to 80% of the total power output is delivered by the lower crankshaft. The power available from the upper shaft, already less than lower shaft power because of lower crank lead, is further reduced, insofar as engine output is concerned, by the load of the engine accessories which the upper shaft generally drives.

Modern engines of the opposed-piston design have a number of advantages over single-acting engines of comparable rating. Some of these advantages are: less weight per horsepower developed; lack of cylinder heads and valve mechanisms (and the cooling and lubricating problems connected with them); and fewer moving parts.

Single-acting engines have their own advantages, such as not requiring blowers, if they are of the 4-stroke cycle design. These engines are more efficient if supercharged with a turbocharger which is driven by the otherwise wasted energy of exhaust gases. Certain repairs are easier on a single-acting engine since the combustion space can be entered without removing an entire crankshaft and piston assembly. Because of this you are more likely to work on single-acting engines than on opposed-piston engines.

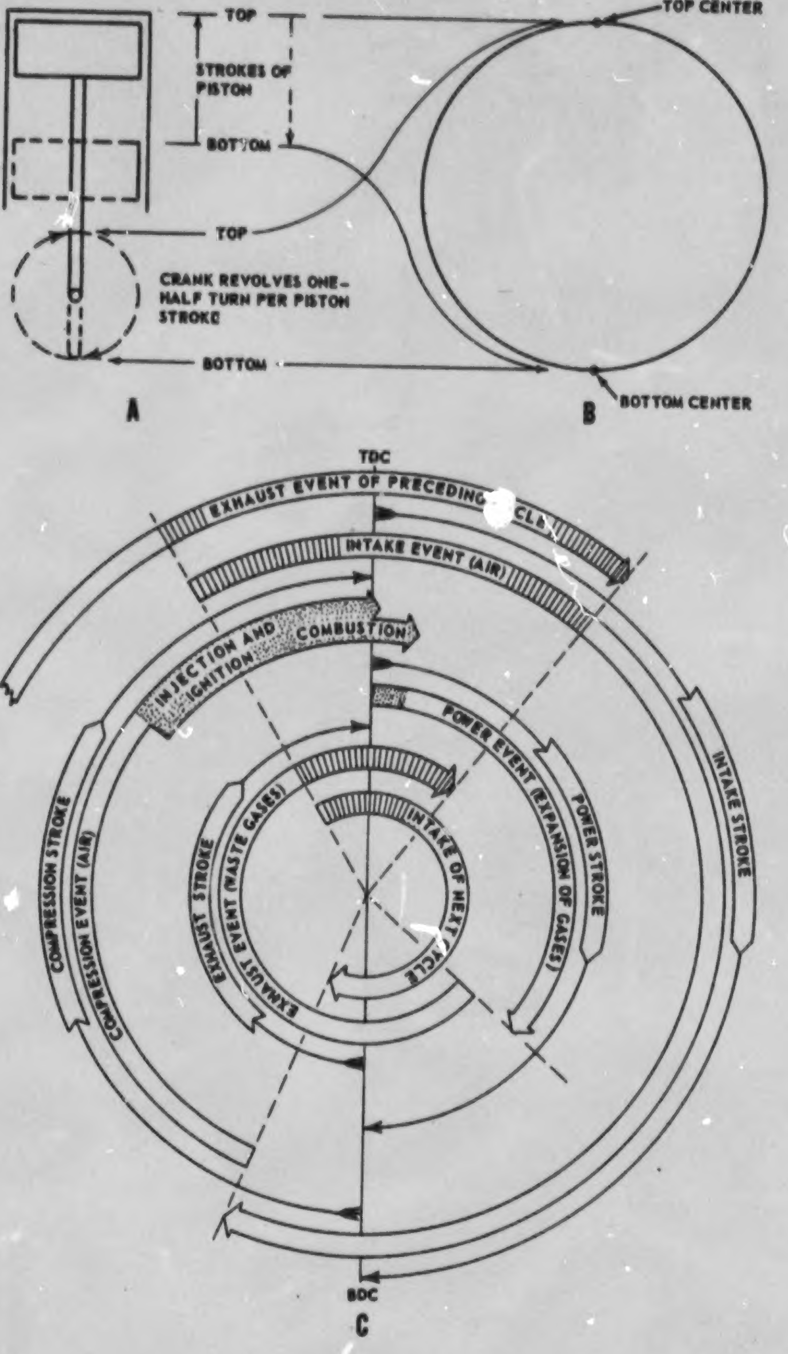

TOP
STROKES OF PISTON
BOTTOM
TOP CENTER
TOP
CRANK REVOLVES ONE-HALF TURN PER PISTON STROKE
BOTTOM
BOTTOM CENTER
A
B
TDC
EXHAUST EVENT OF PRECEDING CYCLE
INTAKE EVENT (AIR)
INJECTION AND IGNITION
COMBUSTION
POWER EVENT (EXPANSION OF GASES)
POWER STROKE
INTAKE STROKE
INTAKE OF NEXT CYCLE
EXHAUST
EXHAUST EVENT (WASTE GASES)
EXHAUST STROKE
COMPRESSION EVENT (AIR)
COMPRESSION STROKE
BDC
C

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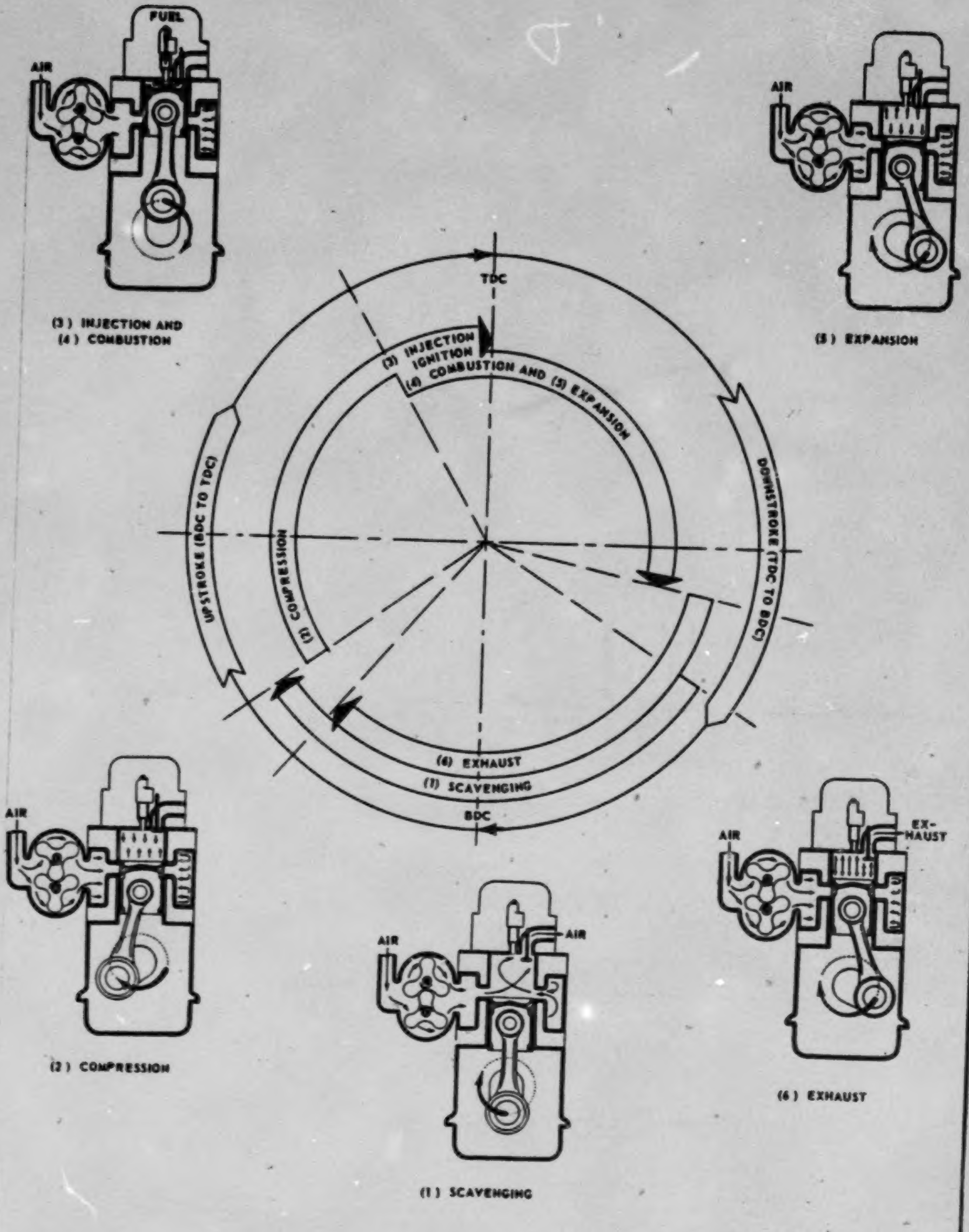
Figure 2-1.—Strokes and events of a 2-stroke cycle diesel engine.


FUEL
AIR
(3) INJECTION AND
(4) COMBUSTION
AIR
(5) EXPANSION
TDC
(3) INJECTION
IGNITION
(4) COMBUSTION AND (5) EXPANSION
DOWNSTROKE (TDC TO BDC)
UPSTROKE (BDC TO TDC)
(2) COMPRESSION
(6) EXHAUST
(1) SCAVENGING
BDC
AIR
(2) COMPRESSION
AIR
AIR
(1) SCAVENGING
AIR
EX-
HAUST
(6) EXHAUST

54.19(75)A

Figure 2-2.—Relationship of events and strokes in a 4-stroke cycle diesel engine.

CHAPTER 3

PRINCIPAL STATIONARY PARTS OF AN ENGINE

Most internal-combustion engines of the reciprocating type are constructed in much the same general pattern. Although engines are not exactly alike, there are certain features common to all, and the main parts of most engines are similarly arranged. Since gasoline engines and diesel engines have the same basic structure, the descriptions of the engine parts and systems in this and the following chapters apply generally to both types of engines. However, differences do exist and we shall point these out wherever they occur. The main differences in diesel and gasoline engines exist in the fuel systems and the methods of ignition.

The main parts of an engine, excluding accessories and systems, may be divided into two principal groups: (1) those parts that do not involve motion, i.e., the structural frame and its components and related parts; and (2) those parts which involve motion. This chapter deals with the main stationary parts of an engine. Information about the moving parts of an engine is given in the chapters which follow.

The stationary parts of an engine maintain the moving parts in their proper relative position so that the gas pressure produced by combustion can "push" the pistons and rotate the crankshaft. The prime requirements for the stationary parts of Navy diesel engines are: ample strength, low weight, minimum size, and simplicity of design. Strength is necessary if the parts are to withstand the extreme forces developed in an engine; space limitations aboard ship make minimum weight and size essential; and simplicity of design is of great importance when maintenance and overhaul are involved.

ENGINE FRAMES

The term "frame" is sometimes used to identify a single part of an engine; it is also used to identify several stationary parts fastened together to support most of the moving engine parts and engine accessories. We shall use the latter meaning in our discussion.

The designs of modern engine frames differ somewhat from earlier designs. Some of the earlier frames were referred to as the A-frame type, the crankcase type, the trestle type, and the staybolt or tie-rod type. These early frames were named according to their shape or the manner in which the parts were fastened together. Many of the features common to early engine frames have been incorporated in frames of more recent design.

As the load-carrying part of the engine, the frame of the modern engine may include such parts as the cylinder block, crankcase, bedplate or base, sump or oil pan, and end plates.

CYLINDER BLOCKS

The cylinder block is the part of the engine frame that supports the engine's cylinder liners and head or heads. The blocks for most large engines are of welded steel construction. In this type of construction, the block is made of steel forgings and plates, which are welded horizontally and vertically for strength and rigidity, and located where loads occur. Deck plates are generally fashioned to house and hold the cylinder liners. The uprights and other members are welded with the deck plates into one rigid unit. Blocks of small high-speed engines may be of cast iron en bloc (in one piece) construction.

42

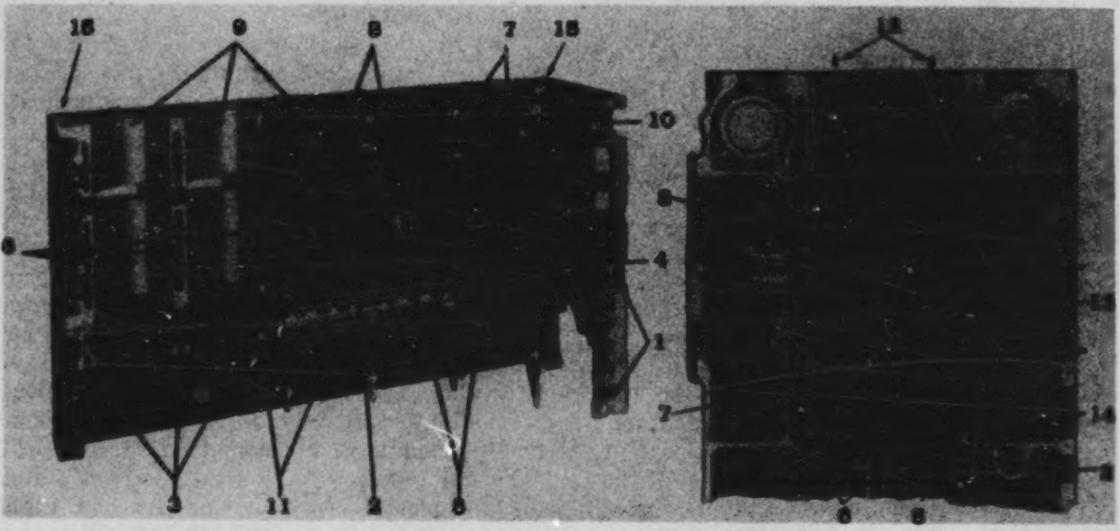
A cylinder block may contain passages to allow circulation of cooling water around the liners. However, if the liner is constructed with integral cooling passages, the cylinder block generally does not have cooling passages. Many blocks have drilled lube oil passages. Most 2-stroke cycle engines have air passages in the block.

In other words, a passage that is an integral part of an engine block may serve as a part of the engine's cooling system, lubricating system, or air system. Generally, we think of one cylinder block in connection with all cylinders of an engine; however, some engines have one cylinder block for each cylinder or for each pair of cylinders. Engines with V-type or X-type cylinder arrangements may have a separate block for each bank of cylinders. Examples of cylinder blocks common to Navy service are shown in figures 3-1, 3-2, and 3-3.

In figure 3-1 the crankcase is an integral part of the block, and the entire unit is a one-piece casting of alloy cast iron. Transverse members provide rigidity and strength, ensuring alignment of the bores and bearings under all loads. The block is bored (9 in the figure) to receive the cylinder liners. Note the air inlet ports (8) in the cylinder bores and the water jackets (6) which extend the full length of the bores. Air space surrounds the water jackets. Through this space, commonly called the air box (7), air is conducted from the blower to the inlet ports. Other parts, which are cast integral with this type of block, are the upper halves of the main bearing seats (11), handholes (unnumbered), bore for the cam or balance shaft (10), lubricating oil passages (1, 2, and 3), and coolant passages (4 and 5).

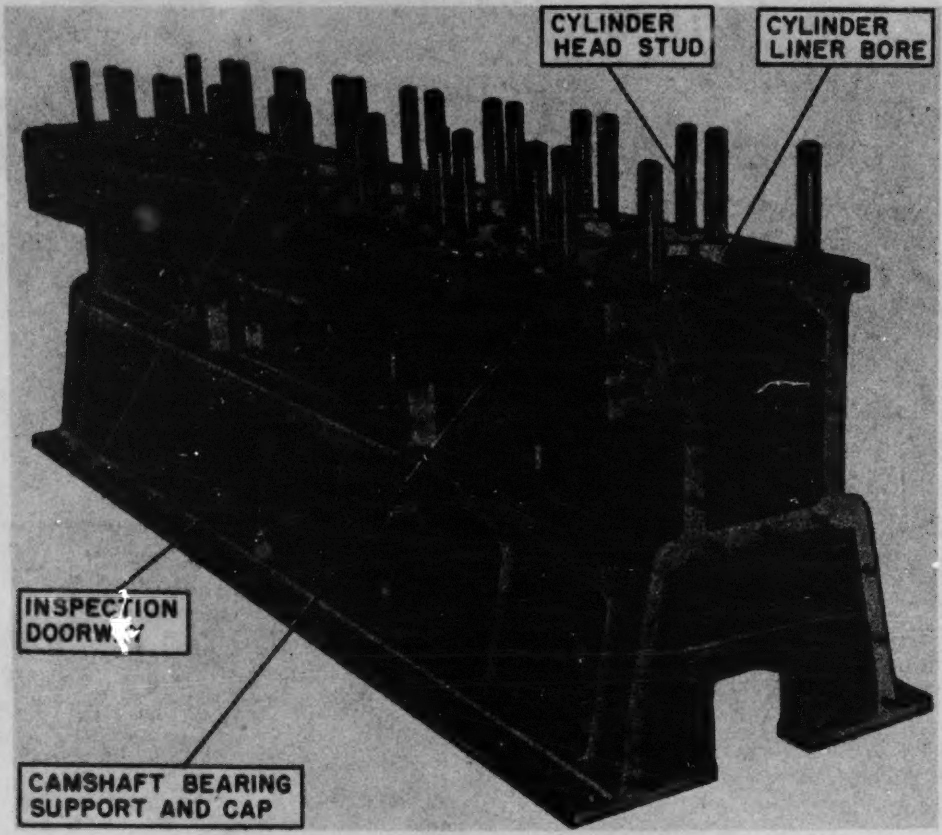
The cylinder block shown in figure 3-2 is somewhat larger than the one just described. It is constructed of welded steel forgings and steel plate. This type of block is secured to a separate engine base and, when the two parts are bolted together, they form the frame for the main bearings which carry the crankshaft. Note that the camshaft bearing supports, consisting of forged transverse members, are an integral part of the block. Pads are welded to the block and are machined to carry engine parts and accessories. The block shown has no water passages because each cylinder liner and cylinder head has its own water jacket.

The cylinder block of another large diesel engine is shown in figure 3-3. The welded steel



75.13X

Figure 3-1.—Cylinder block and crankcase (cast or "en bloc" construction).



75.14

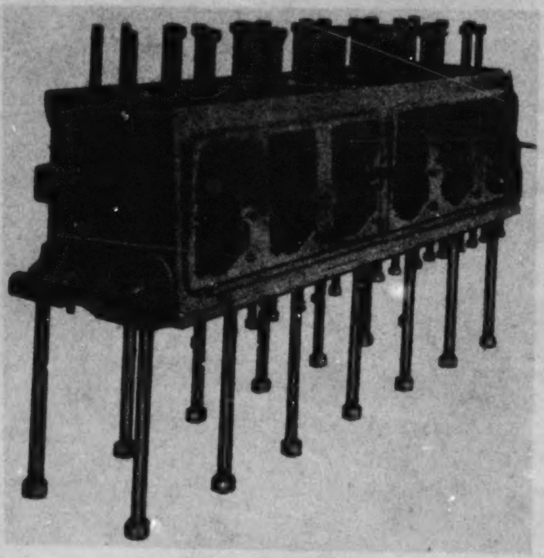
Figure 3-2.–Cylinder block (welded steel plates and forgings).

structure provides rigid support for the cylinder cooling jackets, liners, and heads. The long bolts on the bottom of the block secure the unit to a separate engine part such as the crankcase which we shall discuss later in this chapter.

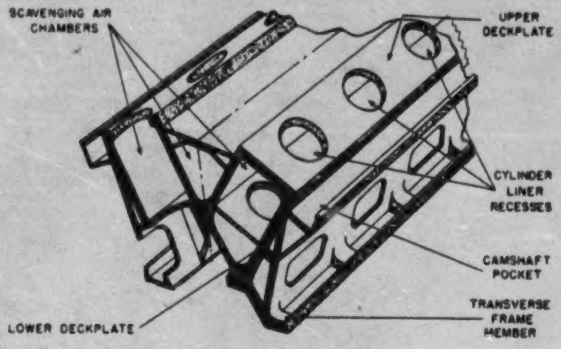
The three cylinder blocks discussed so far are all from engines with an in-line cylinder arrangement. The block illustrated in figure 3-4 is representative of blocks constructed for some engines with the V-type cylinder arrangement. Blocks of this type are usually constructed of forgings and steel plates welded together. In the V-type construction, the upper and lower deck plates of each side of the V are bored to receive the cylinder liners. The space between the deck plates and the space between the two banks form the scavenging air chamber, or air box. In some blocks of this type, the liner bore in the lower deck plate is made with a groove that serves as a cooling water inlet for the liner. Some V-type blocks are constructed with the mounting pads for the main bearings' seats as parts of the forged transverse members at the bottom of the block. In some blocks, the lower bearing seats for the camshaft are located in a pocket which is an integral part of the block. Note the camshaft pocket in figure 3-4.

CRANKCASES

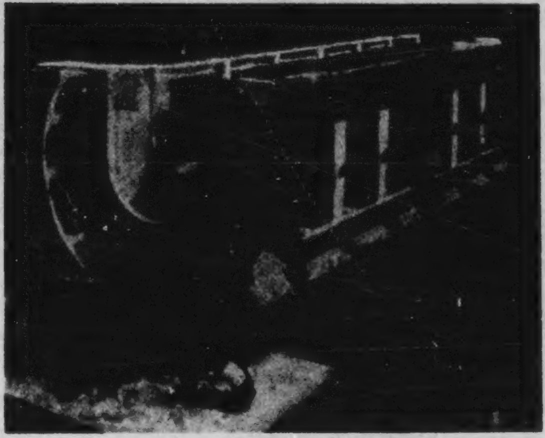
The engine frame part that serves as a housing for the crankshaft is commonly called



75.15
Figure 3-3.—Cylinder block (welded steel plates and forgings).



75.16
Figure 3-4.—An example of a V-type cylinder block construction.



75.18
Figure 3-5.—Crankcase.

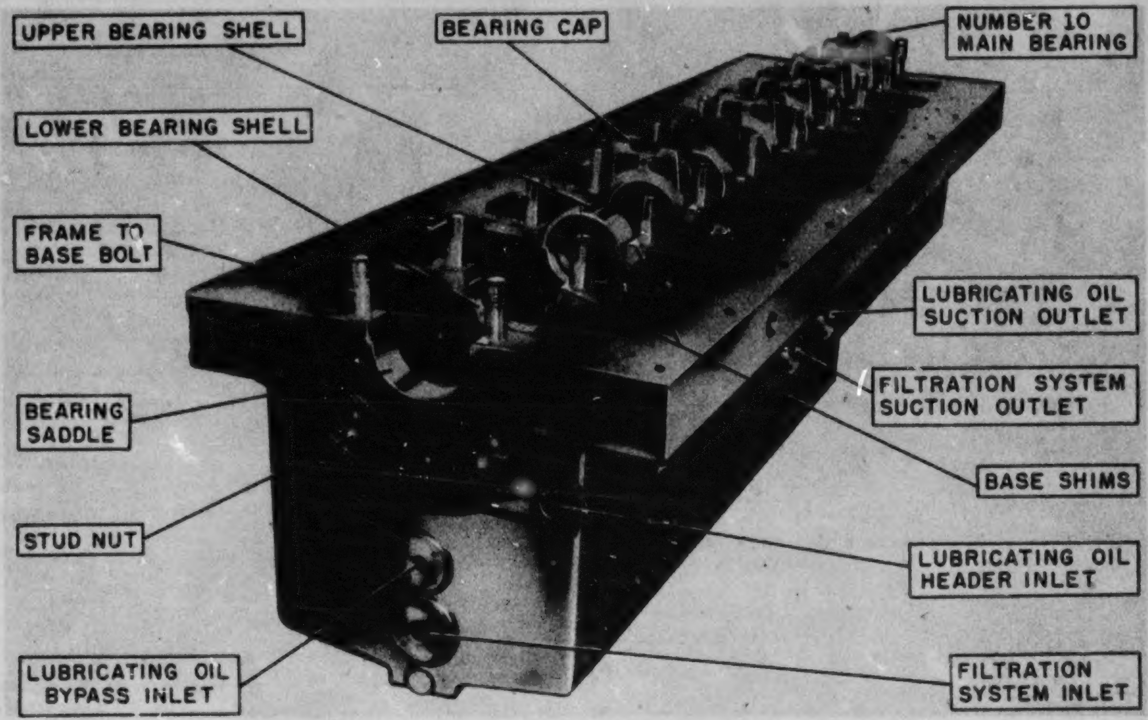
the crankcase. In some engines, the crankcase is an integral part of the cylinder block (fig. 3-1 and 3-2), requiring an oil pan, sump, or base to complete the housing. In others, the crankcase is a separate part and is bolted to the block. Figure 3-5 illustrates a crankcase of the latter type which is used with the block shown in figure 3-3. This crankcase is an all-steel welded structure which incorporates the bolting flanges, the main bearing saddles, and an oil trough. A crankcase of this type is sometimes called the main engine base.

BEDPLATES AND BASES

In large engines of early design, a bedplate supported the main bearings. The bedplate was bolted to the crankcase and an oil pan was bolted to the bedplate. In some large engines of more modern design, the support for main bearings is provided with a part called the base. Figure 3-6 illustrates such a base, which is used with the block shown in figure 3-2. This type of base serves as a combination bedplate and oil pan. Although similar to the crankcase shown in figure 3-5, the base in figure 3-6 requires the engine block to complete the frame for the main engine bearings. (In the crankcase shown in figure 3-5, however, the crankshaft and the main bearings were mounted and secured completely within the crankcase.)

SUMPS AND OIL PANS

A reservoir for collecting and holding the engine's lubricating oil is a necessary part of the engine structure. The reservoir may be called a


UPPER BEARING SHELL
BEARING CAP
NUMBER 10 MAIN BEARING
LOWER BEARING SHELL
FRAME TO BASE BOLT
LUBRICATING OIL SUCTION OUTLET
FILTRATION SYSTEM SUCTION OUTLET
BEARING SADDLE
BASE SHIMS
STUD NUT
LUBRICATING OIL HEADER INLET
LUBRICATING OIL BYPASS INLET
FILTRATION SYSTEM INLET

75.20

Figure 3-6.—Engine base.

sump, oil trough, or an oil pan, depending on its design, and is usually attached directly to the engine. However, in dry sump engines, the sump may be located apart from the engine. Wherever it is located, the reservoir serves the same purpose.

In the crankcase and the engine base shown in figures 3-5 and 3-6, the oil sump is part of the base or crankcase and has functions other than just as an oil reservoir. Many of the smaller engines do not have a separate base or crankcase; instead, they have an oil pan, which is secured directly to the bottom of the block. The block shown in figure 3-1 uses such a pan. Usually, the oil pan serves only as the lower portion of the crankshaft housing and as the oil reservoir.

END PLATES

Some engines have flat steel plates attached to each end of the cylinder block. End plates add rigidity to the block and provide a surface to which may be bolted housings for such parts as gears, blowers, pumps, and generators. An end plate and gasket for the block in figure 3-1 are shown in figure 3-7.

ACCESS OPENINGS AND COVERS

Many engines, especially the larger ones, have openings in some part of the engine frame. (See figures 3-2 and 3-3.) These openings permit access to the cylinder liners, main and connecting rod bearings, injector control shafts, and various other internal engine parts. Access doors are usually secured with handwheel or nut-operated clamps and are fitted with gaskets to keep dirt and foreign material out of the engine's interior. On some engines, the covers (sometimes called doors or plates) to access openings are constructed to serve as safety

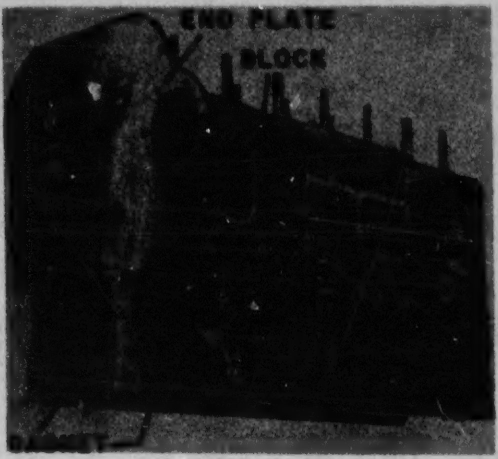


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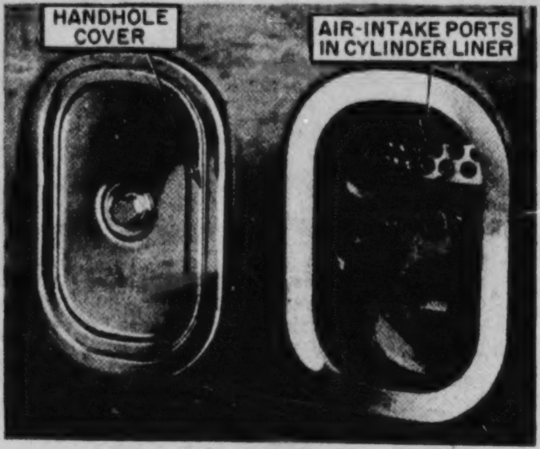
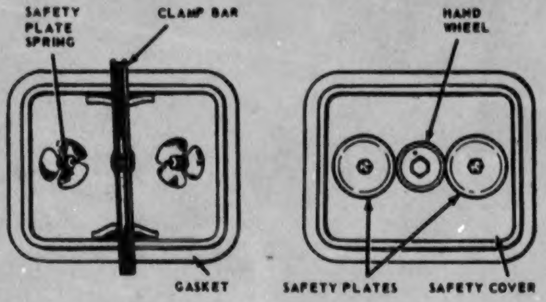
Figure 3-7.—Front end plate and block.



75.22X

Figure 3-8.—Cylinder handhold cover.

devices. A safety cover is one equipped with a spring-loaded pressure plate. The spring maintains a pressure that keeps the plate sealed under normal operating conditions. In the event of a crankcase explosion or extreme pressure within the crankcase, the excess pressure overcomes the spring tension, and the plate in



75.23X

Figure 3-9.—Safety type crankcase handhole cover. Left view, inside of cover. Right view, outside of cover.

the safety cover acts as an escape vent. The release of excess pressure helps to minimize damage to the engine.

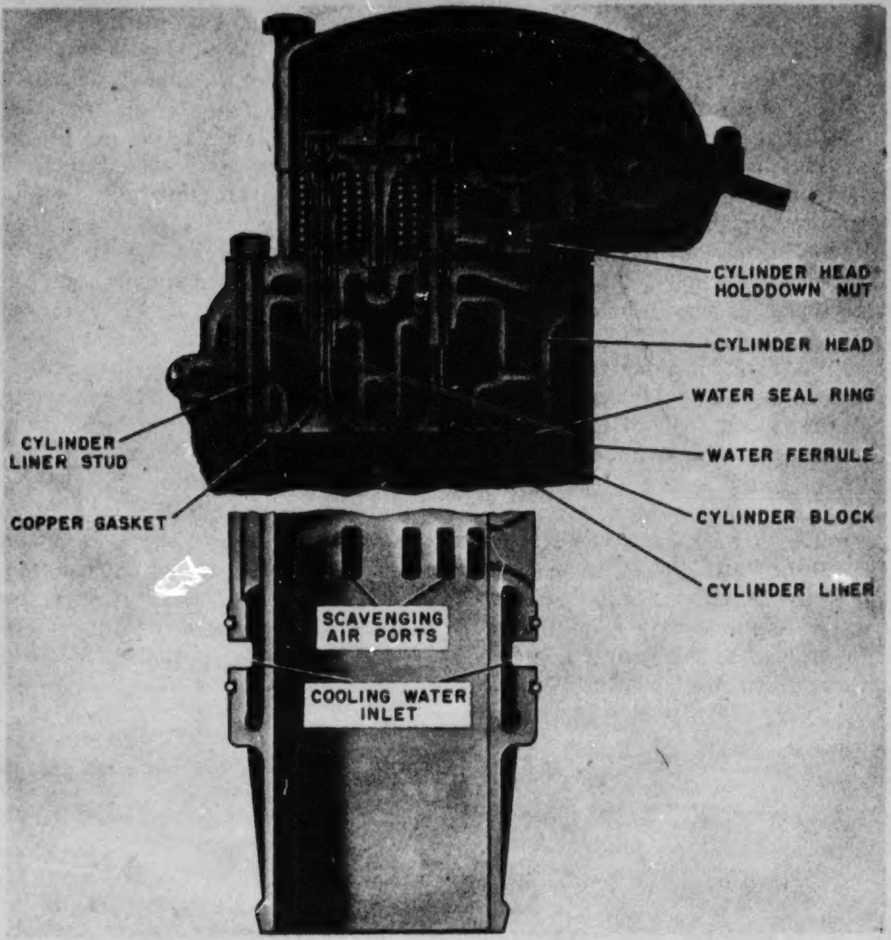
A typical access opening and cover are shown in figure 3-8. The cross section of this cover and its position on the block can be seen in the right-hand view of figure 3-1. A safety cover and its parts are shown in figure 3-9.

BEARINGS

The bearings of an engine make up an important group of parts. Some bearings remain stationary in performing their function while others move. One principal group of stationary bearings in an engine are those that support the crankshaft. These bearings are generally called main bearings. (See figures 3-1 and 3-6.) You will find additional information on these and other bearings in later chapters in connection with related moving parts.

CYLINDER ASSEMBLIES

The cylinder assembly completes the structural framework of an engine. As one of the main stationary parts of an engine, the cylinder assembly, along with various related working parts, serves to confine and release the gases. For


CYLINDER HEAD HOLDDOWN NUT
CYLINDER HEAD
WATER SEAL RING
WATER FERRULE
CYLINDER BLOCK
CYLINDER LINER
CYLINDER LINER STUD
COPPER GASKET
SCAVENGING AIR PORTS
COOLING WATER INLET

75.24X

Figure 3-10.—Principal stationary parts of a cylinder assembly.

purposes of our discussion, the cylinder assembly consists of the head, the liner, the studs, and the gaskets (fig. 3-10). The other engine parts shown in figure 3-10, many of which involve motion, are discussed later in this manual.

The design of the parts of the cylinder assembly varies considerably from one type of engine to another. Regardless of differences in design, however, the basic components of all cylinder assemblies function, along with related moving parts, to provide a gas-tight and liquid-tight space. Differences other than in design will be found in cylinder assemblies. For example, a gasket is necessary between the head and block of most cylinder assemblies. However, such gaskets are not used on all engines. When a gasket is not a part of the assembly, the mating surfaces of the head and block are accurately machined to form a seal between the two parts. Other differences in cylinder assemblies exist, some of which are pointed out in the discussion that follows.

CYLINDER LINERS

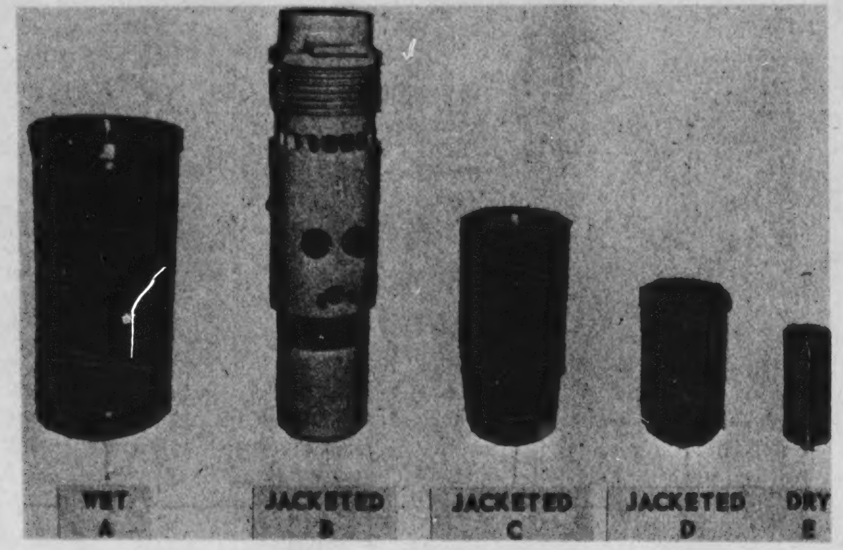
The barrel or bore in which an engine piston moves back and forth may be an integral part of the cylinder block, or it may be a separate sleeve or liner. The first type, common in gasoline engines, has the disadvantage of not being replaceable. When excessive wear occurs in a barrel of this type, the barrel must be rebored and honed. Reconditioning of this nature cannot be repeated indefinitely and, in time, the entire block must be replaced. Another disadvantage is the inconvenience, especially in large engines, of removing the entire cylinder block from a ship in order to recondition the cylinders. For these reasons, practically all diesel engines are constructed with replaceable cylinder liners. The cylinder liners we shall discuss are representative of those used in diesel engines.

The material of a liner must withstand the extreme heat and pressure developed within the cylinder and, at the same time, must permit the piston and rings to move with a minimum of friction. Close-grained cast iron is the material most commonly used for liner construction; however, steel is sometimes used. Some liners are plated on the wearing surface with porous chromium. Chromium has greater wear-resistant qualities than other materials. Also, the pores in the plating tend to hold the lubricating oil and thereby aid in maintaining the lubrication film which is necessary to reduce friction and wear.

Five replaceable-type cylinder liners are shown in figure 3-11. These liners illustrate some of the differences in the design of liners and the relative size of the engines represented.

Types of Liners

Cylinder liners may be divided into two general classifications or types: dry or wet. The dry-type liner does not come in contact with the coolant; instead, it fits closely against the wall of the cooling jacket in the cylinder block. With the wet-type liner, the coolant comes in direct contact with the liner. Wet liners may have a cooling water space between the engine block and liner, or they may have integral cooling passages. Liners with integral cooling passages are sometimes referred to as water-jacketed liners.



75.25

Figure 3-11.—Cylinder liners of diesel engines.

DRY LINERS.—Liners of this type have relatively thin walls compared with liners of the wet type. The smallest liner in figure 3-11E is of the dry type. The cross section of this liner can be seen in the right-hand view of figure 3-1. Note that the coolant circulates in passages in the block and does not come in contact with the liner.

Liners of the dry type are installed in some engines with a press fit and in others with a loose fit. Some engines using the type of block shown in figure 3-1 are fitted with press fit liners and others have liners with a loose fit. Manufacturers recommend that, when replacements are necessary, liners with a press fit be replaced with those having a loose fit. In such cases, the liners for both press and loose fits are identical internally. Therefore, when replacements are made, the cylinder bores in the block must be honed to a larger diameter to permit the loose fit. All liners in a block must have the same type fit.

Liners with a press fit require special tools for installation and removal. In small engines, liners with a loose fit can usually be removed by hand after the liner has been loosened.

WET LINERS.—In wet type liners that do not have integral cooling passages, the water jacket is formed by the liner and a separate jacket which is a part of the block frame. (See figure 3-12.) A seal must be provided at both the combustion and crankshaft ends of the cylinders to prevent leakage. Generally, the seal at the combustion end of a liner consists of either a gasket under a flange or a machined fit. Rubber or neoprene rings generally form the seal at the crankshaft end of the liner. Liners of this type are so constructed as to permit lengthwise expansion and contraction, and the walls are strong enough to withstand the full working pressure of the combustion gases.

In figure 3-11A, the liner with the largest diameter is an example of this type of wet liner. Note the grooved flange at the top and the seal ring grooves at the lower end. The groove in the flange and the tongue of the cylinder head make a metal-to-metal joint and seal. The joint between the flange and the cooling jacket is sealed with a nonhardening sealing compound. A cross section of a wet type liner is shown in figure 3-12.

WATER-JACKETED LINERS.—A cylinder sleeve of this type has its own coolant jacket as an integral part of the liner assembly. The jacket may be cast on, shrunk on, or sealed on the liner. The water is admitted into the lower section of the jacket and leaves through the top, as illustrated in figure 3-13. The liner shown is that of a 4-stroke cycle engine. Most 2-stroke cycle engines are equipped with water-jacketed liners, since such liners provide the most effective means of establishing a watertight seal around the ports.

Another feature of some liners is the counterbored area. Such an area is identified in figure 3-13B. The counterbore extends downward to the top point of travel of the firing ring. The diameter of the liner in the counterbored area is slightly larger than the diameter in the area of piston ring travel. If the diameter of the liner were the same throughout its length, the increase in diameter in the ring contact area would result in the formation of a

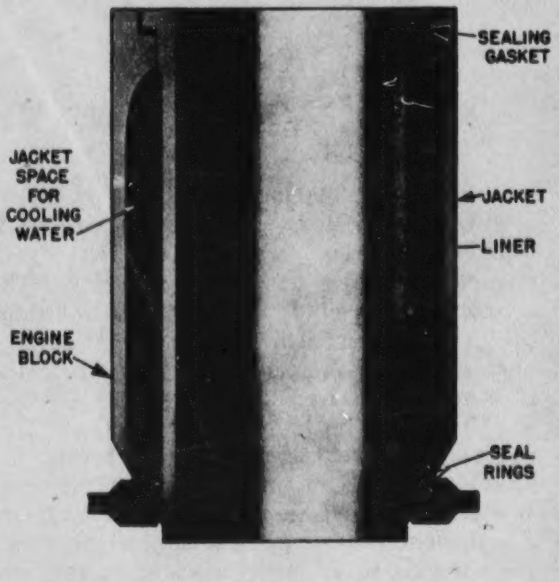


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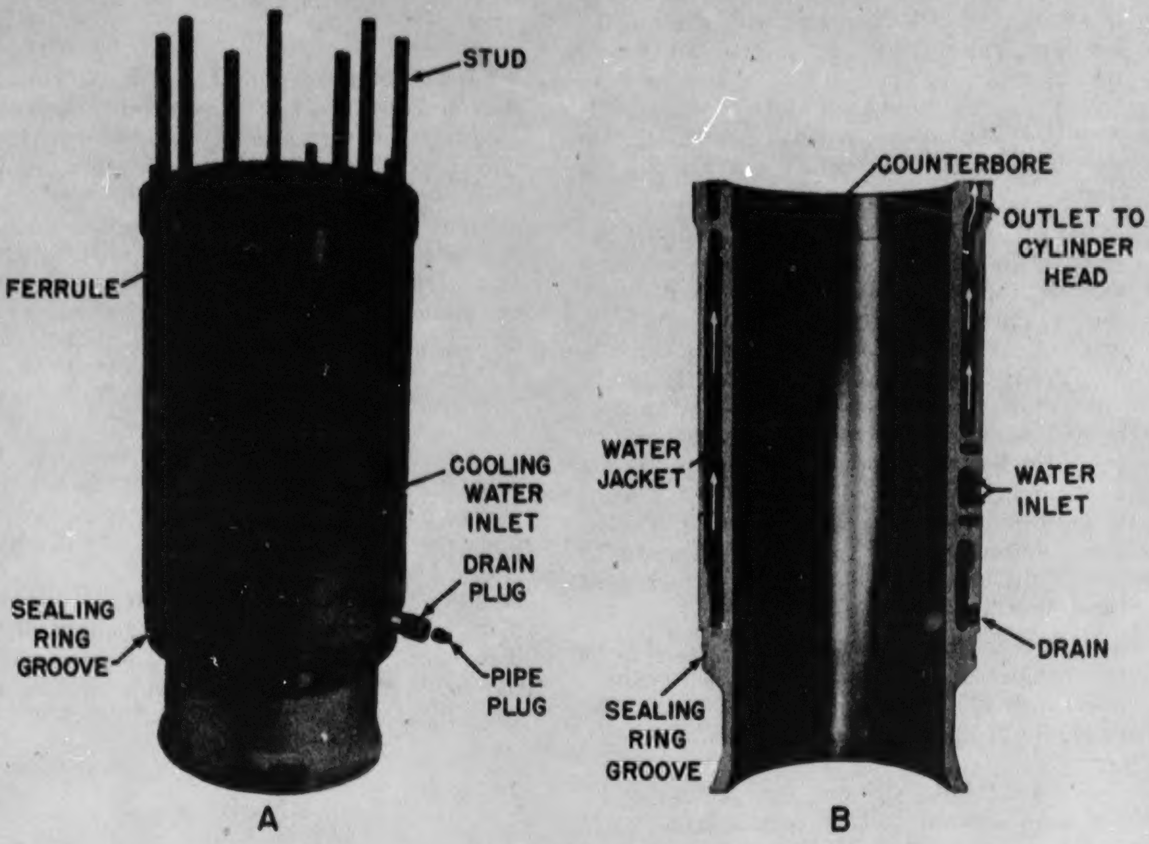
Figure 3-12.—Cross section of a wet type cylinder liner.


STUD
FERRULE
COOLING WATER INLET
DRAIN PLUG
SEALING RING GROOVE
PIPE PLUG
A
COUNTERBORE
OUTLET TO CYLINDER HEAD
WATER JACKET
WATER INLET
DRAIN
SEALING RING GROOVE
B

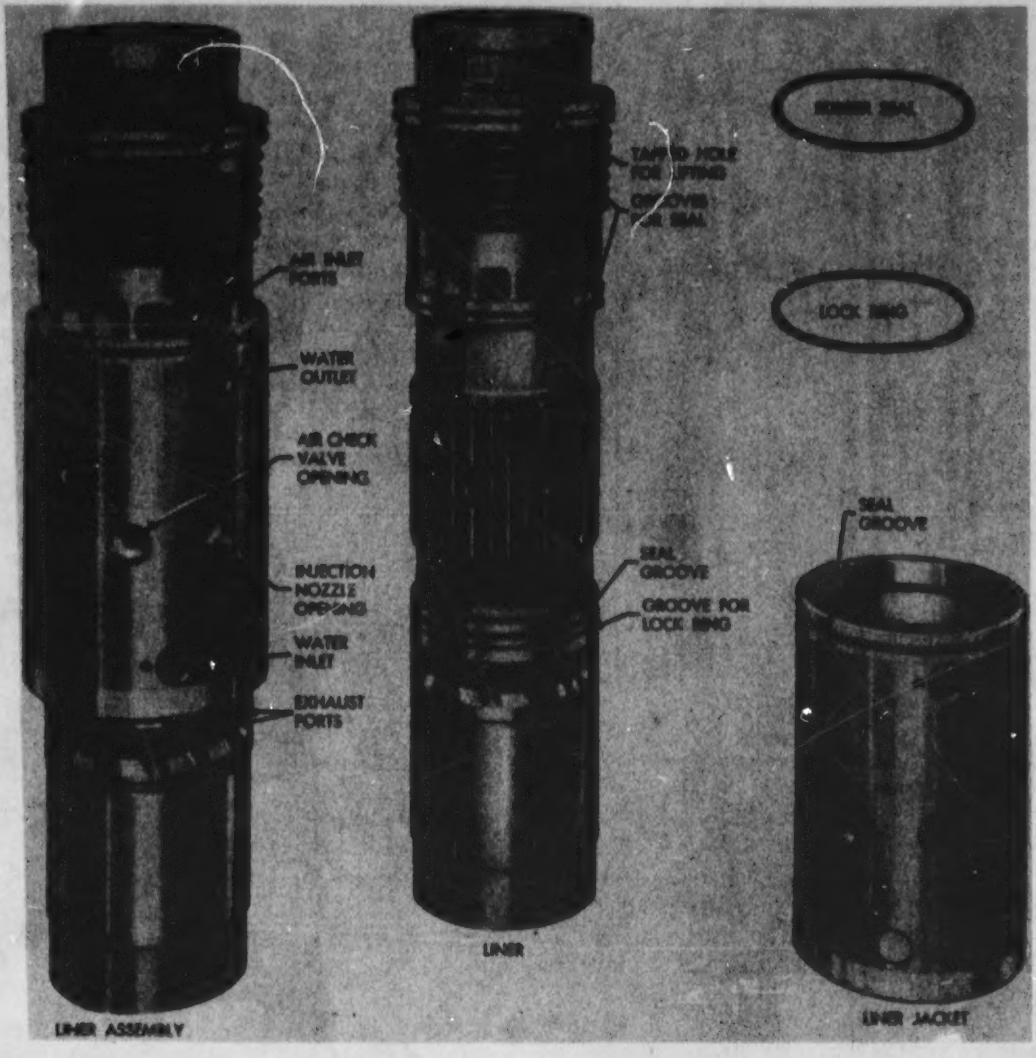
75.27

Figure 3-13.—Jacket-type liner.

ridge or lip on the liner surface at the upper limit of firing ring travel. A lip on the surface of a liner may cause broken piston rings and, possibly, extensive damage to an engine. The counterbore prevents formation of such a ridge or lip. (After extensive engine operation, the liner surface may wear in the area where the rings make contact.)

The liner in figure 3-13 and liners C and D in figure 3-11 have cast-on jackets; that is, the jacket is cast as an integral part of the liner. Whereas in the longest liner shown in figure 3-11B, instead of being cast as an integral part of the liner, the water jacket is sealed on the liner with rubber seal rings. Details of a liner assembly with a sealed-on jacket are shown in figure 3-14.

Of the four jacket-type liners shown (figures 3-11, 3-13, and 3-14) and discussed, note that three have ports. In the largest of these three (fig. 3-14) the location of the ports eliminates the seal of the water jacket as a problem with respect to the air ports. In the other two liners (C and D in fig. 3-12), there is no problem of leakage since the ports are cast as a part of the assembly. In the cast jacket-type liner, the water jacket is formed by the inner and outer walls of the liner. The ports divide the water space into lower and upper spaces, which are connected by vertical passages between the ports. This type of construction is illustrated in figure 3-15. The cross section is that of the liners shown in figure 3-11D.


AIR INLET PORTS
WATER OUTLET
AIR CHECK VALVE OPENING
INJECTION NOZZLE OPENING
WATER INLET
EXHAUST PORTS
LINER ASSEMBLY
TAPPED HOLE FOR LIFTING
GROOVES FOR SEAL
SEAL GROOVE
GROOVE FOR LOCK RING
LINER
RUBBER SEAL
LOCK RING
SEAL GROOVE
LINER JACKET

75.28X

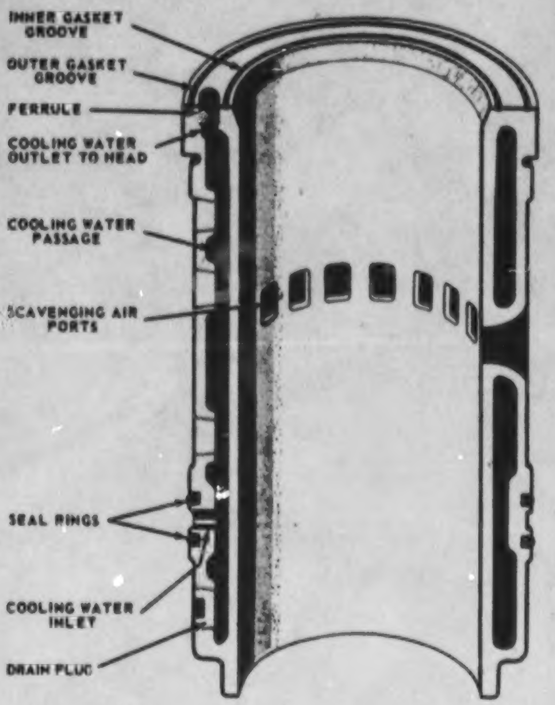
Figure 3-14.—Cylinder liner assembly with sealed-on jacket.

Repair of Liners

Repair procedures for liners vary, depending on the engine. Troubles, which may require repair of the cylinder liners, are cracks, scoring, obstructed ports, or excessive wear. If an inspection or test of the cylinder liner indicates that it must be removed for repair or replacement, follow the instructions given on the appropriate Maintenance Requirement Card (MRC) or in the manufacturer's technical manual for the particular type of engine. Figure 3-16 illustrates the method generally used to remove a cylinder liner.

If it becomes necessary to remove the cylinder liner of an engine, proceed as follows:

1. Drain the water from the engine.
2. Remove the cylinder head.
3. Remove the piston(s).


INNER GASKET GROOVE
OUTER GASKET GROOVE
FERRULE
COOLING WATER OUTLET TO HEAD
COOLING WATER PASSAGE
SCAVENGING AIR PORTS
SEAL RINGS
COOLING WATER INLET
DRAIN PLUG

75.29X

Figure 3-15.—Cross section of cast jacket-type liner with air ports.

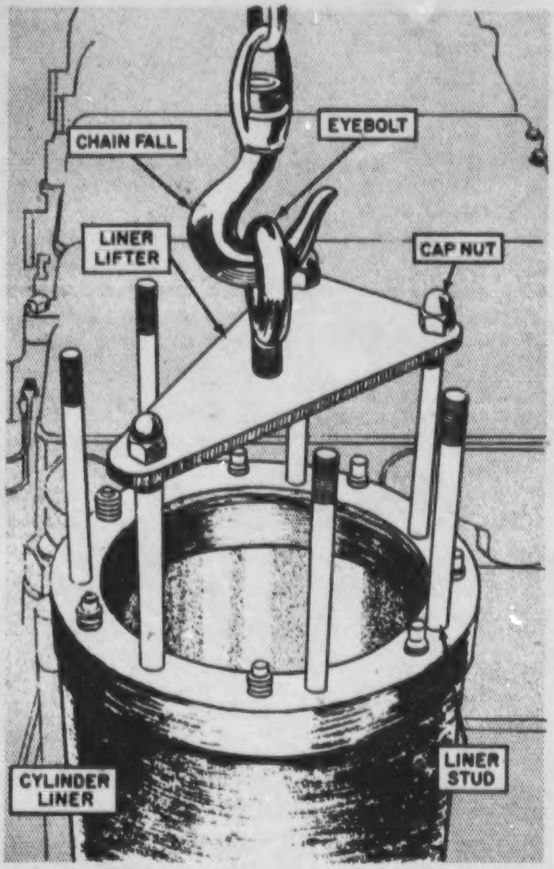
4. Attach the special liner puller to the liner studs and tighten the nuts by hand. (The nuts must be hand tightened; if a wrench is used, the threads on both nuts and studs may be damaged.)

5. Attach the hook of the chain fall and pull slightly until the liner breaks free (fig. 3-16). If the liner fails to break loose immediately, you should apply pressure at the bottom. To do this, place a block of wood on the crankshaft throw, and force it up against the liner by rotating the turning gear.

6. Lift the liner up until it clears the top of the engine block and remove it to a safe place. It may be necessary to rotate the liner slightly while removing it from the engine block.

CRACKED, BROKEN, AND DISTORTED LINERS.—Cracks in liners may logically be suspected when any of the following occur: excessive water in the lubricating oil, an accumulation of water in a cylinder of a secured engine, an abnormal decline in the water level of the expansion tank, excessive temperature or fluctuating pressure of the cooling water (when combustion gases blow into the cooling passages) or oil in the cooling water of an operating engine.

If you cannot locate cracks by visual inspection, you must use other methods. Hydrostatic testing is one method and removing the liners from the engine is another. To check liners with integral cooling passages, plug the outlets and fill the passage with glycol type antifreeze; this liquid will leak from even the smallest cracks. Cracks in dry liners may be


CHAIN FALL
EYEBOLT
LINER LIFTER
CAP NUT
CYLINDER LINER
LINER STUD

75.31

Figure 3-16.—Removing a cylinder liner.

more difficult to locate because there is no leakage water to leak through such cracks. You may need to use magnaflux equipment to locate cracks in dry liners.

Cylinder liners may crack because of poor cooling, improper fit of piston or pistons, incorrect installation, foreign bodies in the combustion space, or erosion and corrosion.

IMPROPER COOLING, which generally results from restricted cooling passages, may cause uneven heating of liners, resulting in liner failure due to thermal stress. Scale formation on the cooling passage surfaces of liners may also cause uneven heating; wet liners are subject to scale formation. Scale may be removed by following the procedures outlined in chapter 233 (9412) of *NavShips' Technical Manual.*

Proper cooling of dry liners requires clean contact surfaces between the liner and cylinder block. Particles of dirt between these surfaces cause air spaces which are poor conductors of heat. Films of oil or grease on these mating surfaces also offer resistance to the flow of heat. DISTORTION, WEAR, or BREAKAGE may result if a liner is not properly seated. Causes of improper liner seating may be metal chips, nicks, or burrs, or improper fillets. In figure 3-17 an improper fillet on the cylinder deck prevents proper liner seating. To correct an improper fillet, grind it down until the lower surface of the flange seats properly on the mating surface of the cylinder deck.

An oversized sealing ring may cause improper positioning of the liner. As the sealing ring is overcompressed, the rubber loses its elasticity and becomes hard, which may result in distortion of the cylinder.

Use feeler gages to check the clearance between the mating surfaces. If the manufacturer's technical manual specifies the distance from the cylinder deck to the upper surface of the liner flange, use this dimension to check on the seating of the liner.

OBSTRUCTIONS in the combustion chamber may be destructive not only to the liner but also to the cylinder head and other parts. EROSION AND CORROSION may take place in a few isolated spots and weaken a liner sufficiently to cause cracks. Replacement is the only satisfactory means of correcting cracked, broken, or badly distorted cylinder liners.

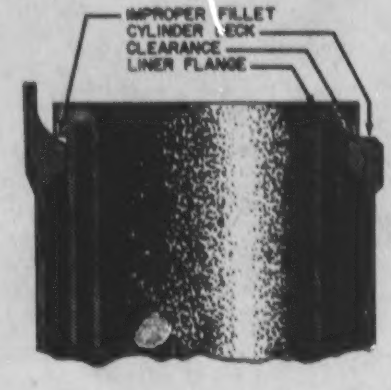


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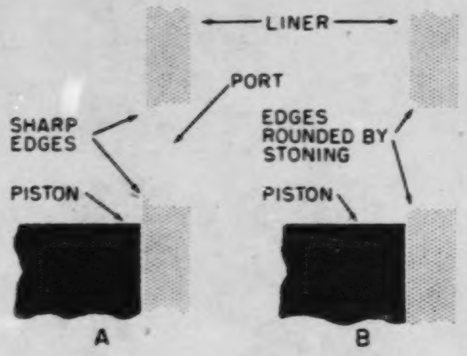
Figure 3-17.—Improperly seated cylinder liner.

SCORED CYLINDER LINERS.—Scoring may be in the form of deep or shallow scratches in the liner surface. With most liner scoring, there will be corresponding scratches on the piston and piston rings. The symptoms of scoring may be low firing or compression pressure and rapid wear of piston rings. The best method for detecting scoring is visual inspection through liner ports, through the crankcase housing with pistons in top position, or when the engine is disassembled.

Scored cylinder liners may be caused by broken pistons rings, a defective piston, improper cooling, improper lubrication, or the presence of foreign particles. Dust particles drawn into an engine cylinder will mix with the oil and become an effective but undesirable lapping compound that may cause extensive damage. We cannot overemphasize the importance of keeping the intake air clean. Another precaution that should be taken is to see that when an engine is being assembled, no metal chips, nuts, bolts, screws, or tools remain in the cylinder when the head is replaced.

Pistons and rings which are badly worn permit blowby of combustion gases. Not only is operating efficiency reduced, but there is also a greater tendency for scoring, both because of the increased temperature and because blowby



75.33

Figure 3-18.—Liner ports before and after stoning.

may reduce the oil film until metal-to-metal contact takes place. Inspect the pistons and rings carefully. A piston with a rough surface (such as one that has seized) will cause scoring of the liner.

Scoring as a result of insufficient lubrication or dirt in the lubricating oil can be prevented if lubricating equipment (filters, strainers, and centrifuges) is maintained properly. Lube oil must be purified in accordance with required procedures.

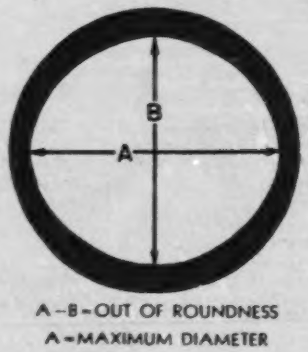
Repair of scored liners is not generally undertaken by ship's force. Spare liners are installed. When necessary, liners with minor scoring may be kept in service, if the cause of scoring is eliminated, and the minor defects can be corrected. The surface of the liner must be inspected carefully, especially in the region next to the ports, for any burrs, projections, or sharp edges that will interfere with piston and ring travel. Most projections can be removed by handstoning, using a fine stone. A liner, before and after the ports were stoned, is shown in figure 3-18.

EXCESSIVELY WORN LINERS.—The best method of finding excessive wear is to take measurements of the cylinder liner with inside micrometer calipers. Two types of liner wear to be checked are illustrated in figure 3-19. Excessive maximum diameter results from general wear equally around the cylinder. Out-of-roundness is produced by the piston thrusting against one or two sides of the cylinders.

Clearance between a piston and a liner is generally checked by micrometer measurements of both parts. On smaller engines, you can use a feeler gage. Clearance in excess of that specified by the manufacturer is generally due to liner wear, which normally is greater than piston wear.

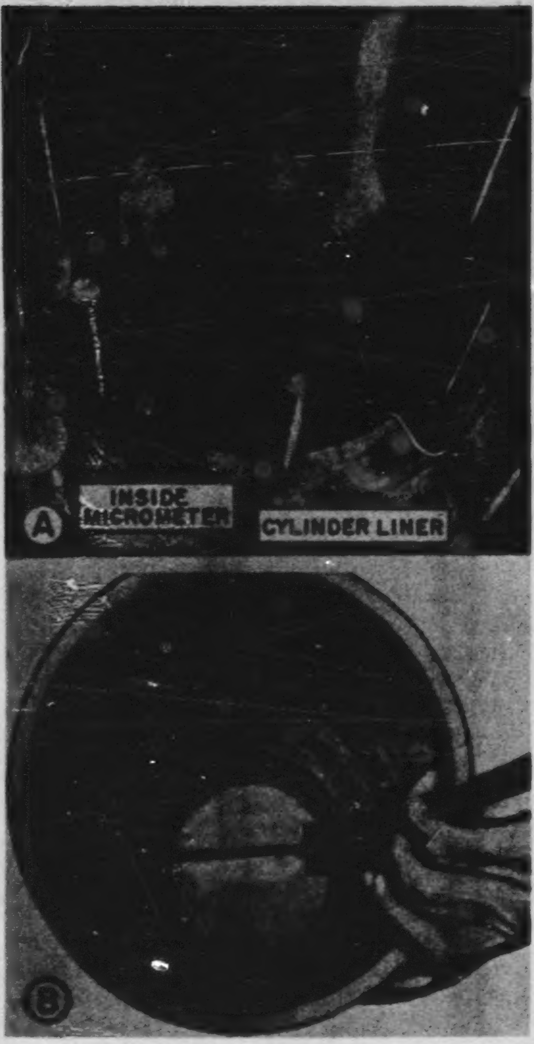
Measurements for determining liner wear should be taken at three levels. Make the first measurement slightly below the highest point to which the top ring travels; make the next measurement slightly above the lowest point of compression ring travel; and make the third measurement at a point about midway between the first two. (All readings should be recorded, so that rapid wear of any particular cylinder liner will be evident to the operator.) If wear or out-of-roundness exists beyond specified limits, the liner should be replaced. Figure 3-20 shows two examples of taking inside measurements. The liner shown in figure 3-20B requires at least twice as many measurements as other types of liners because it is from an opposed piston engine.

You will not get accurate measurements unless you properly position the caliper or gage in the liner. Common errors in positioning are illustrated in A and B of figure 3-21. Hold one end of the caliper firmly against the liner wall, as shown in A of figure 3-20. You can then move the free end back and forth, and up and down,



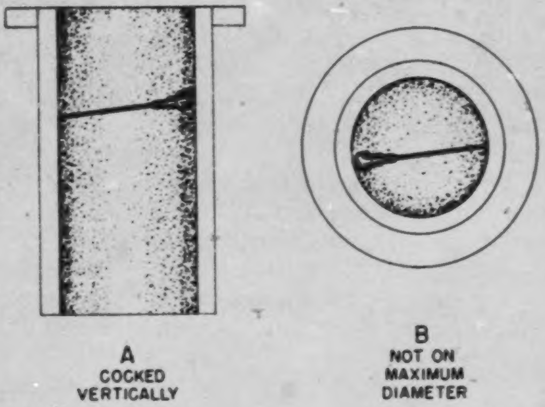
75.34

Figure 3-19.—Measurements for determining liner wear.


A
INSIDE MICROMETER
CYLINDER LINER
B

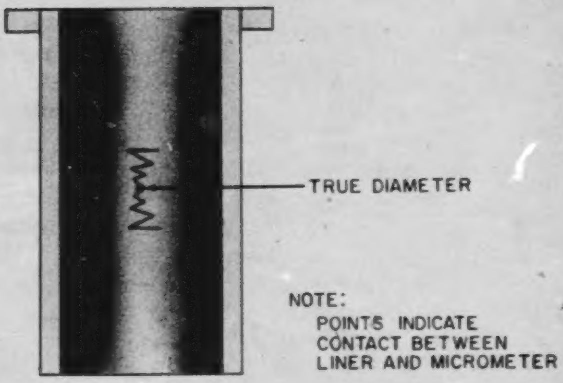
75.35X

Figure 3-20.—Measuring the inside of a cylinder liner.


A
COCKED
VERTICALLY
B
NOT ON
MAXIMUM
DIAMETER

75.36

Figure 3-21.—Errors to avoid when taking liner measurements.


TRUE DIAMETER
NOTE:
POINTS INDICATE
CONTACT BETWEEN
LINER AND MICROMETER

75.37

Figure 3-22.—Trace of caliper end when determining true diameter of a liner.

until you establish the true diameter of the liner. The moving end will trace a patch similar to that illustrated in figure 3-22.

Considerable experience in using an inside micrometer or cylinder gage is necessary to ensure accuracy. As a precaution against error, it is a good practice for two persons to take the liner measurement; then any discrepancy between the two sets of readings can be rechecked.

Excessive or abnormal wear of cylinder liners may be caused by insufficient lubrication, dirt, improper starting procedures, or if the cooling water temperature is too low.

The cooling water of an engine should always be maintained within the specified temperature ranges. If the temperature is allowed to drop too low, corrosive vapors will condense on the liner walls.

The lubricating system must be carefully maintained in proper working order. The method of cylinder liner lubrication varies with different engines. The proper grade oil, in accordance with engine specifications, should be used.

The engine must not be operated in a dirty condition. The air box, crankcase, and manifold should be cleaned and maintained in a clean condition, to avoid cylinder wear and scoring. (Attention to the air cleaner, oil filters, and oil centrifuge are the best precautions against the entrance of dirt into the engine.)

Improper starting procedures will cause excessive wear on the liners and pistons. When an engine is first started, some time may elapse before the flow of lubricating oil is complete; also, the parts are cold and condensation of corrosive vapors is accelerated accordingly. These two factors (lack of lubrication and condensation of corrosive vapors) make the period immediately after starting a critical time for cylinder liners. If an independently driven oil pump is installed, it must be used to prime the lube oil system and build up oil pressure before the engine is started. The engine should not be subjected to high load during the warmup period. Follow the manufacturer's instruction manual concerning warm up time and load application for the engine concerned.

Cylinder liners worn beyond the maximum allowable limit should be replaced. You will find the maximum allowable wear limits for engines in the appropriate manufacturer's technical manual or the Diesel Engine Wear Limit Chart available from the Naval Sea Systems Command. In the absence of such specific information, the following wear limits (established by NavSea) apply in general to:

1. Two-stroke cycle engines with aluminum pistons: 0.0025 inch per inch diameter.
2. Slow-speed engines over 18-inch bore: 0.005 inch per inch diameter.
3. All other engines: 0.003 inch per inch diameter.

CYLINDER HEADS

The liners or bores of an internal-combustion engine must be sealed tightly to form the combustion chambers. In most Navy engines, except for engines of the opposed-piston type, the space at the combustion end of a cylinder is formed and sealed by a cylinder head which is usually a separate unit from the block or liner.

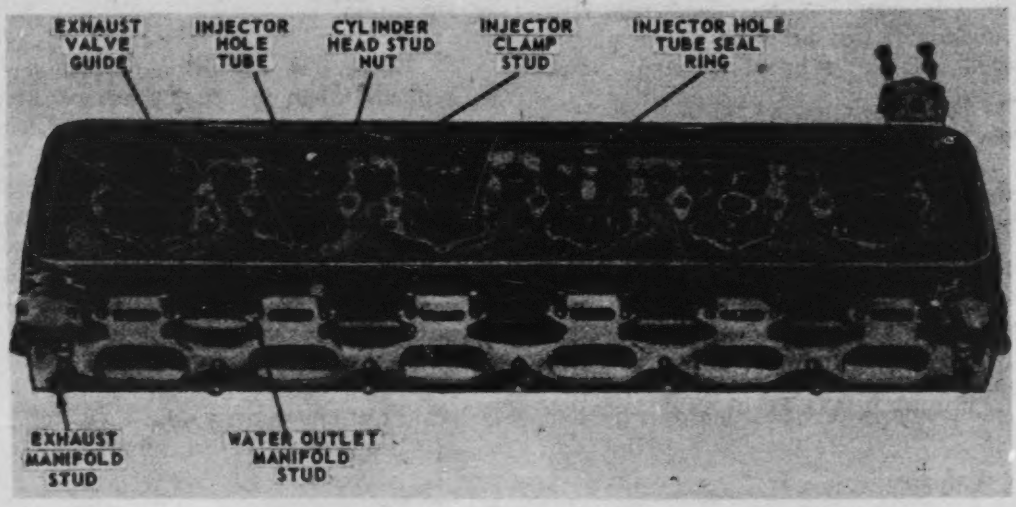
A number of engine parts which are essential to engine operation may be found in or attached to the cylinder head. The cylinder head may house intake and exhaust valves, valve guides and valve seats, or only exhaust valves and related parts. Rocker arm assemblies are frequently attached to the cylinder head. The fuel injection valve is almost always in the cylinder head or heads of a diesel engine, while the spark plugs are always in the cylinder head of gasoline engines. Cylinder heads of a diesel engine may also be fitted with air starting valves, indicator cocks, and safety valves.

The design and material of a cylinder head must be such that it can withstand the rapid changes of temperature and pressure, which take place in the combustion space, and the stress which results from the head's being bolted securely to the block. Cylinder heads are almost always made of heat-resisting alloy cast iron.

The number of cylinder heads found on engines varies considerably. Small engines of the in-line cylinder arrangement use one head for all cylinders. A single head serves for all cylinders in each bank of some V-type engines. Large diesel engines generally have one cylinder head for each cylinder. Some engines use one head for each pair of cylinders.

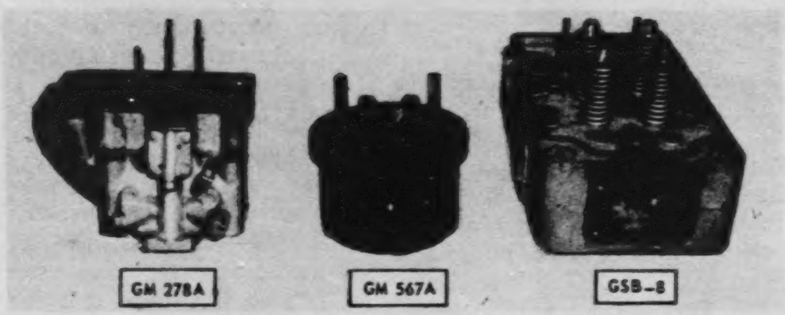
A cylinder head of the type used to seal all cylinders of a block is shown in figure 3-23. This head is used with the block illustrated in figure 3-1. Three heads of the individual-cylinder type are shown in figure 3-24. The head on the right is the type used for each of the cylinders of the block shown in figure 3-2. The other two heads are used on V-type diesel engines. A cross section of the head on the extreme left is shown in figure 3-10.

Coolant passages, common to most cylinder heads, are provided in each of the heads shown in figure 3-24. The coolant enters the head from


EXHAUST VALVE GUIDE
INJECTOR HOLE TUBE
CYLINDER HEAD STUD NUT
INJECTOR CLAMP STUD
INJECTOR HOLE TUBE SEAL RING
EXHAUST MANIFOLD STUD
WATER OUTLET MANIFOLD STUD

75.38X

Figure 3-23.–Cylinder head.


GM 278A
GM 567A
GSB-8

75.39

Figure 3-24.–Cylinder heads for individual cylinders.

the cylinder block or liner and cools the head and attached parts. The connection between the coolant passages in blocks or liners and the head will vary. Such connections may consist of ferrules (fig. 3-10), or similar connections, or outside jumper lines. (See chapter 12 for additional information on engine cooling systems.)

Conditions requiring repair of a cylinder head are, in many ways, similar to those encountered in cylinder liners, and can be grouped, in general, under cracks, corrosion, distortion, and fouling.

Cracks

The symptoms of a cracked cylinder head are the same as those of a cracked liner. Cracks in cylinder heads are best located by visual inspection or a magnetic powder inspection. On some types of engines, a defective cylinder can be located by bringing the piston of each cylinder, in turn, to top dead center, and applying compressed air. When air is applied to a damaged cylinder, a bubbling sound indicates leakage.

When removed from the engine, the cylinder head can be checked for cracks by the hydrostatic test that is used on cylinder liners equipped with integral cooling passages.

Cracks generally occur in cylinder heads on the narrow metal sections between such parts as valves and injectors. The cracks may be caused by adding cold water to a hot engine, by restricted cooling passages, by obstructions in the combustion space, or by improper tightening of studs.

Aboard ship, cracked cylinder heads usually must be replaced. It is possible to repair them by welding, but this process requires special equipment and highly skilled personnel normally found only at repair activities.

Corrosion

Burning and corrosion of the mating surfaces of a cylinder head may be caused by a defective gasket. Although regular planned maintenance ordinarily prevents the occurence of this type of trouble, burning and corrosion may take place under certain conditions. When corrosion and burning occur, there may be a loss of power as a result of combustion gas leakage or water leakage into the combustion space. Other symptoms of leakage may be (1) hissing or sizzling in the area of the head where gases or water may be leaking between the cylinder head and the block, (2) bubbles in the expansion tank sight glass, or (3) overflow of the expansion tank.

Gaskets and grommets that seal combustion spaces and water passages must be in good condition; otherwise the fluids will leak and cause corrosion or burning of the areas contacted. Improper cooling water treatment may also accelerate the rate of corrosion.

In general, cylinder heads that are burned or corroded as a result of gas or water leakage are damaged to such an extent that they must be replaced.

Distortion

Warpage or distortion of cylinder heads is apparent when the mating surfaces of the head and block fail to match properly. If distortion is severe, the head will not fit over the studs. Distortion may be caused by improper welding technique in the repairing of cracks or by improper tightening of cylinder head studs. Occasionally, new heads may be warped because of improper casting or machining processes.

Repair of distorted or damaged cylinder heads is often impracticable. They should be replaced as soon as possible and turned in to the nearest supply activity which will determine the extent of damage and the method of repair.

Fouling

If the combustion spaces become fouled, the efficiency of combustion will decrease. Combustion chambers are designed to create the desired turbulence for mixing the fuel and air; any accumulation of carbon deposits in the space will impair both turbulence and combustion by altering the shape and decreasing the volume of the combustion chamber.

Symptoms of fouling in the combustion spaces are smoky exhaust, loss of power, or high compression. Such symptoms may indicate the existence of extensive carbon formation, or clogged passages. In some engines, these symptoms indicate that the shutoff valves for the auxiliary combustion chambers are stuck.

Combustion chambers may also become fouled because of faulty injection equipment, improper assembly procedures, or excessive oil pumping.

Cleaning of fouled combustion spaces generally involves removing the carbon accumulation. The best method is to soak the dirty parts in an approved solvent and then wipe off all traces of carbon. You may use a scraper to remove carbon, but be careful to avoid damaging the surfaces. If oil pumping is the cause of carbon formation, check the wear of the rings, bearings, pistons, and liners. Replace or recondition excessively worn parts. Carbon formation resulting from improperly assembled parts can be avoided by following the procedure described in the manufacturer's technical manual.

CYLINDER HEAD STUDS AND GASKETS

In most installations, the seal between the cylinder head and the block depends principally upon the studs and gaskets. The studs, or stud bolts, secure the cylinder head to the cylinder block. A gasket between the head and the block is compressed to form a seal when the head is properly tightened.

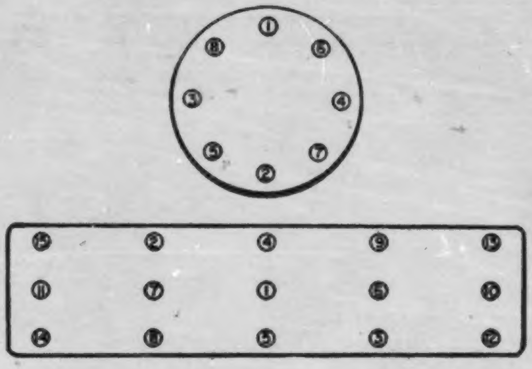
Round rod, generally of alloy steel, is used for cylinder head STUDS. Threads are cut on both ends, and those that screw into the block are generally of a much tighter fit than those on the nut end. A tighter fit in the block aids in preventing the stud from unscrewing when the stud nuts are removed. Usually, studs which are in good condition should not be removed from a cylinder block.

Sets of cylinder head studs in position in cylinder blocks can be seen in figure 3-2 and 3-3.

All stud nuts should be tightened equally and in accordance with specifications given in the manufacturer's technical manual. Overtightening is as undesirable as undertightening. Sometimes studs that are relatively inaccessible are neglected during the periodic checks for tightness. Such an oversight may result in studs coming loose and failing.

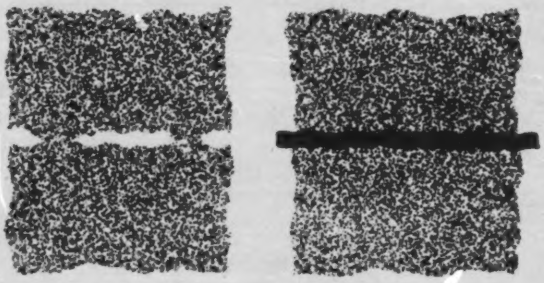
When installing stud nuts, the threads of the studs and the nuts should be carefully cleaned by wire-brushing and applying an approved solvent. Cleaning will minimize wear and distortion of threads resulting from dirt, as well as increase the accuracy of the torque wrench readings. (It is evident that a higher torque wrench reading will be necessary to reach required tension when the threads are dirty than when they are cleaned and well lubricated.)

Figure 3-25 illustrates an order for tightening studs for two types of cylinder heads.



75.40

Figure 3-25.—Order of sequence for tightening cylinder head studs.



A – SURFACE WITHOUT GASKET

B – GASKET IN PLACE

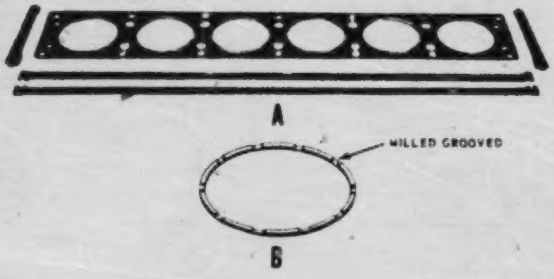
75.41

Figure 3-26.—The principle of a gasket.

This order is not a hard and fast rule but can be followed in the absence of more specific information. Studs are generally tightened sufficiently to seat the cylinder head lightly, finger tight. At least two or three rounds of tightening should be made before bringing all studs up to the specified torque.

Even though gasket design is quite varied, all GASKETS have "compressibility" as a common property. The principle by which this property is put to use in forming a seal between mating parts is illustrated in figure 3-26. Two types of gaskets are shown in figure 3-27.

60



75.42X

Figure 3-27.—Types of gaskets.

The mating surfaces of a cylinder block and head may appear to be quite smooth; however, if highly magnified, existing irregularities can be seen in the surfaces, as illustrated in part A of figure 3-26. Such irregularities, though slight, are sufficient to allow leakage of the combustion gases, oil, or coolant unless some compressible material is used between the mating surfaces. The manner in which compressible gasket material fills the openings caused by the irregularities of the two mating surfaces is illustrated in B of figure 3-26.

Material used in the manufacture of gaskets varies as widely as does gasket design. Gaskets are made from copper and other relatively soft metals, laminated steel sheets, fiber, cork, rubber, synthetic rubber, and a combination of materials such as copper and asbestos. Combinations of gaskets, seal rings, and grommets or similar devices may be used to prevent leakage of oil, water, and gas between a cylinder block and head.

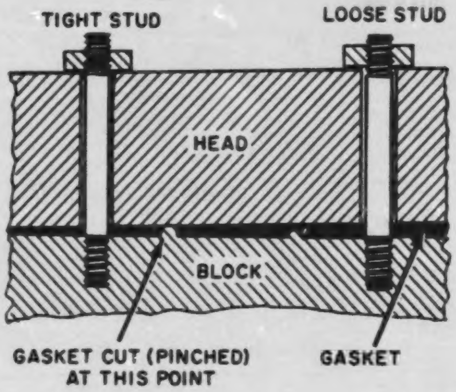
Leakage is the chief trouble encountered with gaskets. Leakage becomes apparent when the compression pressure becomes low, resulting in starting difficulties, or when fluid escapes between the head and block. Sometimes there may be no external leakage from a defective gasket. The only way to positively determine internal leakage is by removing the cylinder head.

Leaky gaskets may be the result of a permanently compressed gasket, improper tightening of cylinder head stud nuts, careless installation of the gasket, or the installation of a damaged or defective gasket.

After prolonged use, gaskets become permanently compressed and lose their ability to conform to irregularities in the machine surfaces. Leakage will occur past the gasket, and the operator will attempt to stop the leakage by tightening the holddown, or cylinder head, nuts. A gasket in very poor condition may not stop leakage even though the nuts are pulled up to the breaking point. If a gasket is torn or burned across an area that must be sealed, it should be renewed. Gaskets should be removed and renewed in accordance with the engine manufacturer's instructions.

Gaskets may also be damaged by tightening the head nuts unevenly or insufficiently. Figure 3-28 illustrates a condition that may occur if the nuts are tightened unevenly. That portion of the gasket below the tight nuts may become pinched or cut, particularly where the mating surfaces or the head and cylinder are not perfect planes.

If the nuts are not tightened to the specified torque wrench reading, the gasket may not be compressed sufficiently to cause it to conform to the irregularities in the machined surfaces. This will prevent proper sealing and allow blowby of the combustion gases, burning of the gasket material, and may result in complete failure of the gasket.



75.43

Figure 3-28.—Effect of uneven tightening on a gasket.

When installing a gasket over the studs, you must be careful NOT to bend, tear, or break the gasket. In some installations, the gaskets do not surround the studs but can be placed in recesses either in the cylinder block or the cylinder head; you must position the gasket properly in the recess to avoid cutting or pinching it when the head is pulled down. In addition, it is important that you use the correct type of gasket; a gasket of improper dimensions may prevent proper sealing of the cylinder head on the cylinder block, and result in stud breakage as well as burned surfaces.

ENGINE MOUNTINGS

The devices used to secure an engine in place are not an actual part of the engine. However, a discussion of these devices is included here since they are obviously essential for installation purposes and since they serve an important part in reducing the possibility of damage to an engine and the mechanism which it drives.

Different terms are used to identify the devices that secure an engine to a ship. Such terms as base, subbase, bed, frame, rails, mountings, and securing devices appear in various engine technical manuals. To avoid confusion with the engine base already discussed in this chapter, we will use subbase to describe the supporting and connecting pedestal between an engine and the structure of a ship. We will identify the devices used to fasten the subbase to the ship as securing devices.

SUBBASE

The size and design of the subbase depends on the engine involved and its use. In many installations, the engine and the mechanism which it drives are mounted on a common subbase. One advantage of mounting both units on a common subbase is that misalignment is less likely than when the units are mounted separately. Diesel engine-generator sets are usually secured to a common subbase.

A different type of mounting involves the use of handfitted chocks, or blocks, between the engine and the structure of the ship. Bolts are used to secure the engine rigidly in place and to maintain alignment. A mounting of the block type is used with the engine base shown in figure 3-6.

SECURING DEVICES

The securing devices used to fasten a subbase to the structure of a ship may be classified, in general, as rigid or flexible. Propulsion engines are secured rigidly to avoid misalignment between the engine, reduction gear (or other driven mechanisms), and the propeller shaft. Engines which drive auxiliary equipment may be secured by either rigid or flexible devices.

Bolts

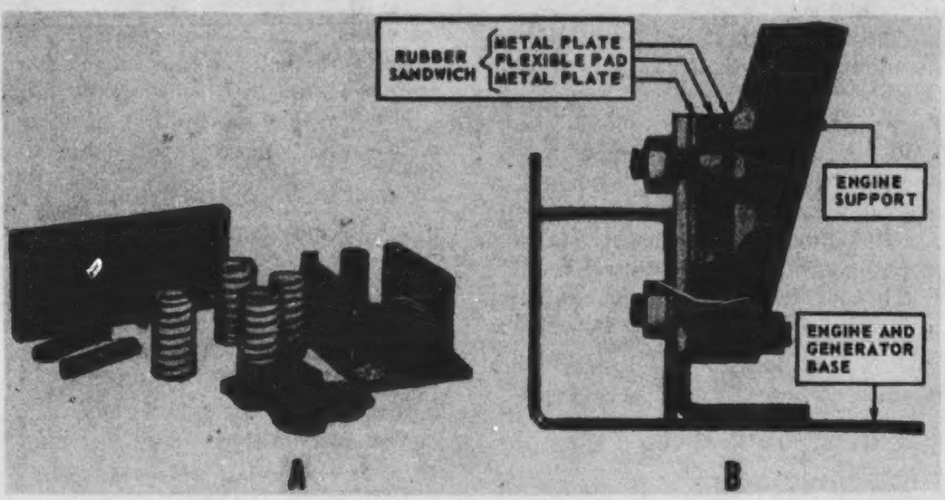
In installations where rigidity is of prime importance, bolts are used as the securing devices. Flexible securing devices are generally used between the subbase of a generator set and the ship's structure. Flexible devices may be placed between the engine and the subbase. Although flexible devices are not necessary for every type of generator set, they are desirable for generator sets which are mounted near the side of the hull, in order to reduce vibration. Flexible devices also aid in preventing damage from shock loads imposed by external forces.

Flexible securing devices are of two general types: the vibration isolator and the shock absorber. Both types may be incorporated in one device.

Vibration Isolator

The isolator is designed to absorb the forces of relatively minor vibrations, which are common to an operating engine. Such vibrations are referred to as high-frequency, small-amplitude vibrations, and they result from an unbalanced condition created by the movement of operating engine parts.

Isolators may be equipped with coil springs or flexible pads to absorb the energy or



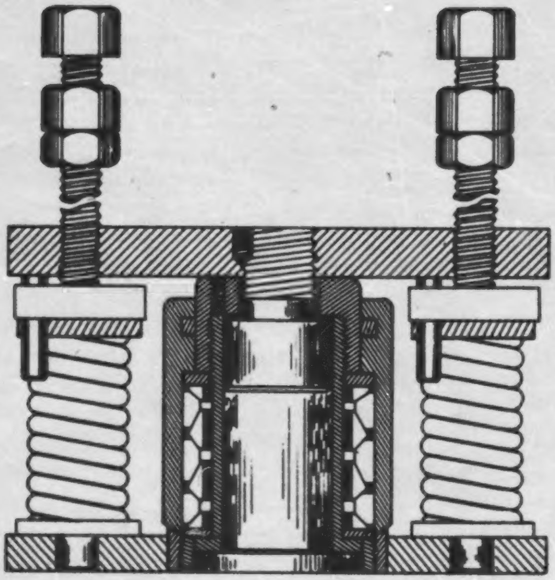
75.45

Figure 3-29.—Vibration isolators.

vibration. An isolator reacts in the same manner, whether it is of the spring type or of the flexible pad type. Examples of both types of isolators are shown in figure 3-29. Four or more spring type isolators, shown in part A are used to support a generator set. The flexible pad or "rubber sandwich" type isolator, shown in part B, is used for mounting small Navy engines. The rubber block in the isolator shown is bonded to steel plates which are fitted for attachment to the engine and subbase.

Shock Absorbers

Shock absorbers are used to absorb vibration forces which are greater than those originating in the engine. Such forces, or shock loads, may be induced by the detonation of depth charges, torpedoes, bombs, etc. The shock absorber operates on the principle of the vibration isolator but incorporates an additional device to protect the engine against severe shock loads. A common type of shock absorber in use in the Navy is illustrated in figure 3-30.



75.46

Figure 3-30.—Shock absorber.

CHAPTER 4

PRINCIPAL MOVING AND RELATED PARTS

Many of the principal parts that are mounted within the main structure of an engine are moving parts. These moving parts convert the power developed by combustion in the cylinder to mechanical energy which is then available for useful work at the output shaft.

In this chapter we will discuss the moving and related parts that seal and compress gases in the cylinder and transmit the power developed in the cylinder. We will also discuss the jacking gear. Other parts that are needed to develop and transmit power, such as timing gears and gear trains, are discussed in later chapters of this manual.

VALVE MECHANISMS

Valve mechanisms of different engines may vary considerably in construction and design, even though the function remains the same. The basic types of valve mechanisms are described briefly in *Fireman*, NAVEDTRA 10520-E. We will go into more detail in the following paragraphs with additional information on valve mechanism troubles. Chapter 5 of this manual describes the operation of valve mechanisms in various types of engines.

VALVES

Intake and exhaust valves used in internal-combustion engines are of the poppet type. Poppet valves have heads with cone-shaped or beveled edges and a bevel seat, which gives the valves a self-centering action.

Exhaust valves are usually made of silicon-chromium steel or steel alloys. Usually, there is a high content of nickel and chromium included in the steel or alloy to resist corrosion caused by high-temperature gases. A hard alloy, such as Stellite, is often welded to the seating surface of the valve head and to the tip of the valve stem. The hard alloy increases the wearing qualities of the surfaces which make contact when the valve closes. Low-alloy steels are generally used for intake valves because these valves are not exposed to the corrosive action of the hot exhaust gases.

Sodium is used in some exhaust valves to aid in cooling the valves. The hollow valve stems are partly filled with sodium. At engine operating temperatures, the sodium melts and splashes up and down inside the valve. The sodium is a very effective way to transfer the heat from the hot exhaust valve head through the stem and valve guides to the engine cooling system.

Regardless of differences in engine construction, certain troubles are common to all applicable parts of valve assemblies.

Intake valves generally give longer periods of trouble-free operation than exhaust valves because the operating temperature of the intake valve is lowered by the air that enters the cylinder.

Sticking Valves

Sticking valves will cause an engine to misfire and will produce unusual noises at the cam follower, push rod, and rocker arm.

61

Improper lube oil or improper fuel will leave RESINOUS DEPOSITS which, if allowed to accumulate, may cause valves to stick. Sometimes a mixture of half lube oil and half kerosene is used to remove resins. This should NOT be used except on parts that have been removed from the engine, since an amount of this mixture settling in the cylinder could cause a serious explosion. There are a number of Navy-approved commercial products that can be used when a complete disassembly is impracticable.

Bent Valves

A valve that hangs open not only prevents the cylinder from firing, but is likely to be struck by the piston and bent so that it cannot seat properly. Symptoms of warped or slightly bent valves will usually show up in the form of damage to the surface of the valve head. To lessen the possibility that cylinder head valves will be bent or damaged during overhaul, NEVER place a cylinder head directly on a steel deck or grating; use a protective material such as wood or cardboard. NEVER pry a valve open with a screwdriver or similar tool.

Weak Springs

Valves may close slowly, or fail to close completely, because of weak springs. At high speeds, valves may "float," thus reducing engine efficiency. Valve springs wear quickly when exposed to excessive temperatures and to corrosion from moisture combining with sulfur that is present in the fuel.

Burned Valves

Burned valves are indicated by irregular exhaust gas temperatures and sometimes by an excessive noise. In general, the principal causes of burned valves are carbon deposits, insufficient tappet clearance, defective valve seats, and valve heads that have been excessively reground.

The principal cause of burned exhaust valves is small particles of carbon that lodge between the valve head and the valve seat. These particles come from incomplete combustion of the fuel or oil that is left by the piston rings in the cylinder. The particles hold the valve open just enough to allow the combustion gases to pass, or leak, at high enough velocities and temperatures to cause the valve head to burn. The valve seat seldom burns because the water jackets surrounding the seat usually provide enough cooling to keep its temperature below a dangerous point. The valve is cooled by several means, including its contact with the valve seat. When carbon particles prevent contact, the heat normally transferred from the valve head to the seat remains in the valve head.

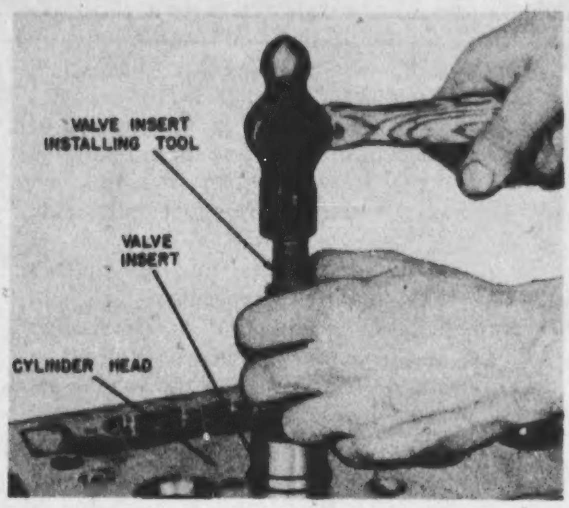
When cleaning carbon from cylinder heads, remove all loose particles from the crevices; be extremely careful so that you do not nick or scratch the valve or seat. Removing the valves from the engine will make it easier to clean the passages and remove the carbon deposits from the underside of the valve heads.

You should check the tappet clearance adjustments at frequent intervals to be certain that they are correct and that the locking devices are secure. The adjustment of valve clearances is discussed later in this chapter.

Most engines are equipped with valve seat inserts made of hard, heat-resisting, alloy steel. Occasionally, a seat will crack and allow the hot gases to leak, burning both the insert and the valve. Sometimes a poor contact between the valve seat insert and counterbore prevents the heat from being conducted away, and the high temperatures, which result, deform the insert. When this occurs, both the seat and the valve will burn; the seat insert must be replaced.

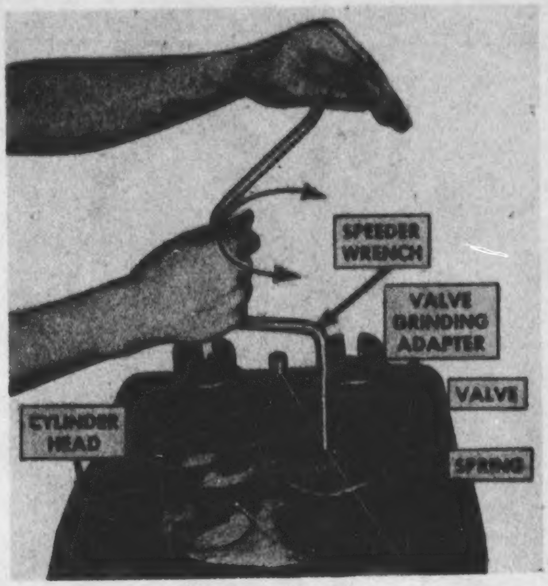
Loose Valve Seats

Loose valve seats can be avoided only by proper installation. Clean the counterbore thoroughly to remove all carbon before shrinking in an insert. Chill the valve seat with dry ice and place the cylinder head in boiling water for approximately 30 minutes; then drive the insert into the counterbore with a valve insert installing tool, as illustrated in figure 4-1.


VALVE INSERT INSTALLING TOOL
VALVE INSERT
CYLINDER HEAD

75.71X

Figure 4-1.–Driving a valve insert into the cylinder head counterbore.


SPEEDER WRENCH
VALVE GRINDING ADAPTER
VALVE
CYLINDER HEAD
SPRING

75.72

Figure 4-2.–Hand grinding a valve and valve seat.

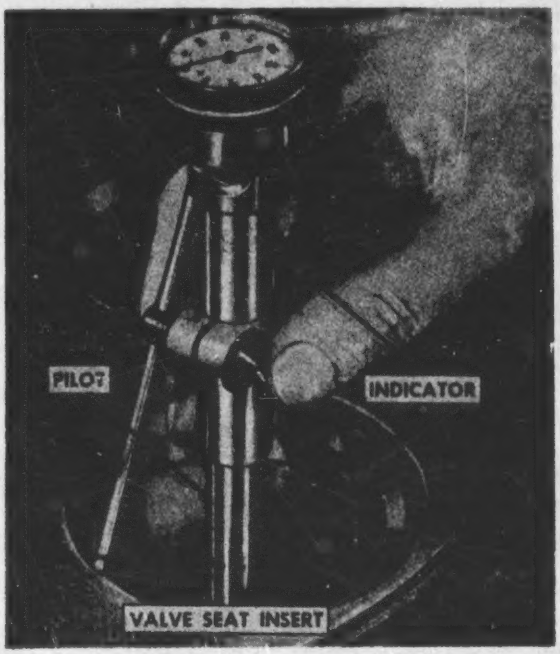
Never strike a valve seat directly. The driving operation must be done quickly, before the insert reaches the temperature of the cylinder head.

When replacing a damaged valve with a new one, inspect the valve guides for excessive wear. If the valve moves from side to side as it seats, you must replace the guides.

Pitting

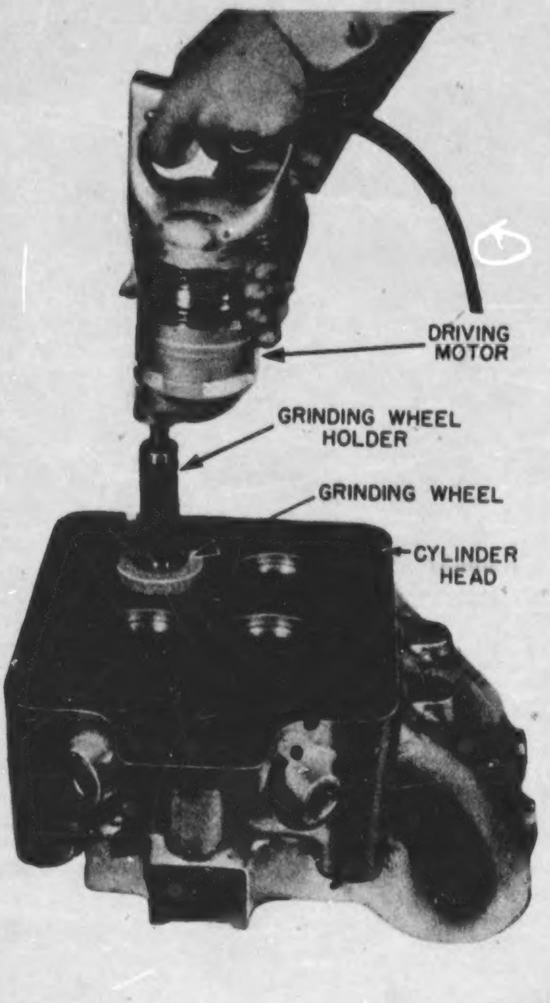
If the valve seat is secured firmly in the counterbore and is free of cracks and burns, you may remove slight damage such as pitting by hand grinding (fig. 4-2). Generally, you will use prussian blue to check the valve and valve seat, but if this is not available, use any thin dark oil paint. Allow the valve to seat by dropping it on the valve seat from a short distance. If the surfaces fail to make complete contact, regrinding is necessary. In any valve reconditioning job, the valve seat must be concentric with the valve guide. You can determine the concentricity with a dial indicator, as shown in figure 4-3.

Hand-grinding methods should be held to a minimum and never used in place of machine


PILOT
INDICATOR
VALVE SEAT INSERT

75.73

Figure 4-3.–Determining concentricity of the valve seat, with a dial indicator.



75.74X
Figure 4-4.—Machine grinding a valve seat.

grinding, in which a grinding stone is used to refinish the seat (fig. 4-4). To machine grind, place the stone on the pilot (fig. 4-3) and engage the grinder. Grind the seat a few seconds at a time and check the seat after each cut until it is free of pits.

The objection to hand grinding the valve to the seat is that a groove or indentation may be formed in the valve face. Since the grinding is done when the valve is cold, the position of the groove with respect to the seat is displaced when the engine is running, because of the extreme temperatures of the valve head over the valve seat. Such a condition is illustrated (greatly exaggerated) in figure 4-5. Note that when "hot," the ground surface of the valve does not make contact at all with the ground surface of the seat. Therefore, hand grinding should be used only to remove slight pitting or as the final and finishing operation in a valve reconditioning job.

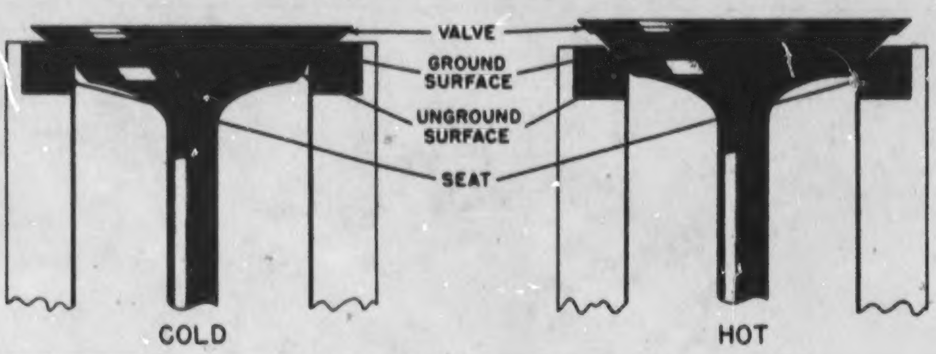
Some valves and seats are not pitted sufficiently to require replacement but are pitted to such an extent that hand grinding would be unsatisfactory. Such valves may be refaced on a lathe (fig. 4-6), and the valve seats may be reseated by power grinding equipment (fig. 4-4). Normally, these operations are done at a repair base or naval shipyard.

Valve heads that are excessively reground to such an extent that the edge is sharp, or almost sharp, will soon burn. A sharp edge cannot conduct the heat away fast enough to prevent burning. It is this factor that limits the extent to which a valve may be refaced.

Broken Valve Springs

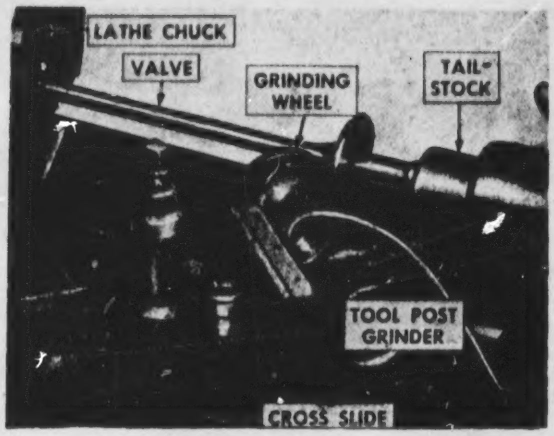
Broken valve springs cause excessive valve noise and may cause erratic exhaust gas temperatures. The actual breakage of the valve springs is not always the most serious consequence. When a spring breaks, it may collapse just enough to allow the valve to drop into the cylinder where it may be struck by the piston. In addition, the valve stem locks or keepers may release the valve and allow it to drop into the cylinder, causing severe damage to the piston, cylinder head, and other nearby parts.

A number of precautions can be taken to prevent or minimize corrosion and metal fatigue which cause valve springs to break. Be reasonably careful when assembling and disassembling the valve assembly. Before reassembly, be sure the valve spring is thoroughly cleaned and inspected. (Use kerosene or diesel fuel for cleaning. NEVER use an alkaline solution; it will remove the protective coating.) The condition of the surface of a valve spring is the best indication of impending failure. (Use magnafluxing to help find cracks which would otherwise be invisible.)



75.75

Figure 4-5.—Excessively hand-ground valves.



75.76

Figure 4-6.—Facing a valve on a lathe.

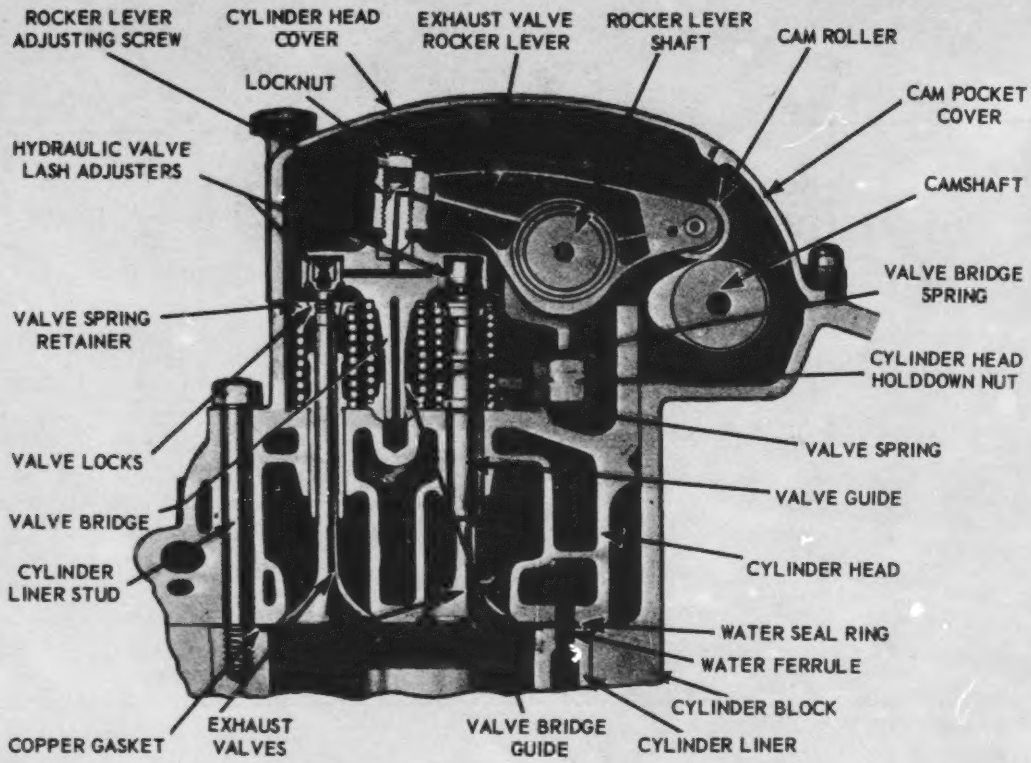
The free length of a valve spring should be within the limits specified in the manufacturer's technical manual. If such information is not available, compare the length of a new spring with that of the used spring. If the length of the used spring is more than 3% shorter than that of the new spring, the used spring should be replaced immediately. Remember, however, that loss of spring tension will NOT always show up as a loss in overall length. Springs may be the proper length but they may have lost enough tension to warrant replacement.

Springs with nicks, cracks, or surface corrosion must NOT be reinstalled in the engine. When the protective coating is nicked, apply a new coating. To minimize corrosive conditions, use clean lube oil, eliminate water leaks, and keep vents open and clean.

Worn Valve Keepers and Retaining Washers

Worn valve keepers and retaining washers may result if valve stem caps (used in some engines) are improperly fitted. Such caps are provided to protect and increase the service life of the valve stems. Trouble occurs when the cap does not bear directly on the end of the stem, but bears instead on the valve stem locks or spring retaining washer. This transmits the actuating force from the cap to the locks or retaining washer, and then to the stem, causing excessive wear on the stem grooves and valve stem locks. As a result, the retaining washers will loosen and the valve stems may break.

An improper fit of a valve stem cap may be due to the use of improper parts or the omission of spacer shims. Steel spacer shims, required in some caps to provide proper clearance, are placed between the ends of the valve stems and the caps; leaving out the shims will cause the shoulder of the cap to come in contact with the locks. When disassembling a valve assembly, determine whether or not shims are used. If so, record their location and exact thickness. Valve caps must be of the proper size, or troubles similar to those resulting from shim omission will occur. Never attempt to use caps or any other valve assembly parts that are worn.


ROCKER LEVER ADJUSTING SCREW
CYLINDER HEAD COVER
EXHAUST VALVE ROCKER LEVER
ROCKER LEVER SHAFT
CAM ROLLER
LOCKNUT
CAM POCKET COVER
HYDRAULIC VALVE LASH ADJUSTERS
CAMSHAFT
VALVE BRIDGE SPRING
VALVE SPRING RETAINER
CYLINDER HEAD HOLDDOWN NUT
VALVE SPRING
VALVE LOCKS
VALVE GUIDE
VALVE BRIDGE
CYLINDER LINER STUD
CYLINDER HEAD
WATER SEAL RING
WATER FERRULE
CYLINDER BLOCK
EXHAUST VALVES
VALVE BRIDGE GUIDE
COPPER GASKET
CYLINDER LINER

75.24X

Figure 4-7.--Valve gear.

Broken Valve Heads

Broken valve heads usually cause damage to the piston, liner, cylinder head, and other associated parts and are generally repairable only by replacement of these parts.

Whether the causes of broken valve heads are mechanical deformation or metal fatigue, you must take every precaution to prevent their occurrence. If a valve head breaks loose, you must make a thorough inspection of all associated parts before making a replacement.

ROCKER ARMS AND PUSH RODS

Rocker arms are part of the valve actuating mechanism, pivoting on a pivot pin or shaft secured to a bracket mounted on the cylinder head. One end of a rocker arm is in contact with the top of the valve stem, and the other end is actuated by the camshaft. In some installations where the camshaft is located near the cylinder head, the rocker arm may be actuated from the cam by the use of hardened-steel rollers (fig. 4-7). In installations where the camshaft is located below the cylinder head, the rocker arms are actuated by push rods. One rocker arm and a bridge (fig. 4-7) may be used in some installations to open two valves simultaneously.

The principal trouble that rocker arms and push rods may have is WEAR which may occur in bushings, or on the pads, end fittings, or tappet adjusting screws.

Worn rocker arm bushings are usually caused by lubricating oil problems. A bushing with excessive wear must be replaced. When installing a new bushing, you usually need to use a reamer for the final fit.

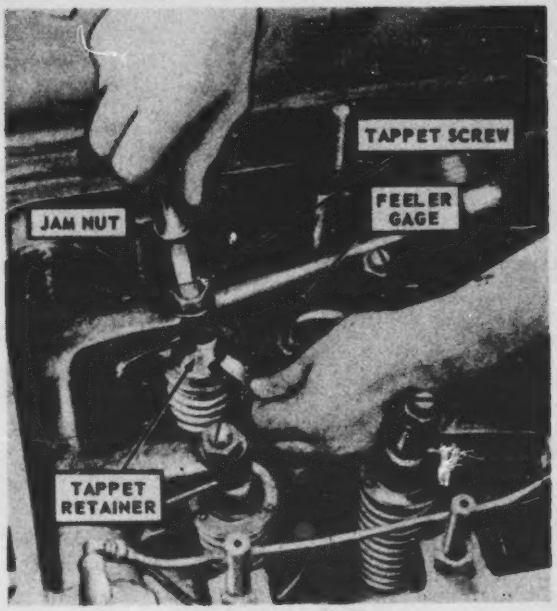
Wear at the points of contact on a rocker arm is generally in the form of pitted, deformed, or scored surfaces. Wear on the rocker arm pads and end fittings is greatly accelerated if lubrication is insufficient or if there is excessive tappet clearance. Push rods are usually positioned to the cam followers and rocker arms by end fittings. The pads are the rocker arm ends that bear on the valve stem or valve stem cap. When the tappet clearance is excessive, the rods shift around, greatly increasing the rate of wear of both the rocker arm and the rod contact surfaces. Worn fittings necessitate the replacement of parts. Continued use of a poor fitting and a worn push rod is likely to result in further damage to the engine, especially if the rod should come loose.

Worn tappet adjusting screws and locknuts usually make it difficult to maintain proper clearances and to keep the locknuts tight. Wear of the adjusting screws is usually caused by loose locknuts, which allow the adjusting screw to work up and down on the threads each time the valve is opened and closed. To prevent this, tighten the locknuts after each adjustment and check the tightness at frequent intervals.

If the threads are worn, the entire rocker arm must be replaced. Do NOT attempt to repair or to use a new tappet adjusting screw except in cases of emergency.

The adjustment of the rocker arm assembly consists chiefly of adjusting the tappets for proper running clearance. The valve clearance for both intake and exhaust valves should be readjusted after overhaul. The procedure for adjusting the rocker arm tappets of a typical 4-stroke cycle engine is as follows:

1. Observe the flywheel indicator, and rotate the engine to top dead center of the compression stroke of the cylinder on which the tappets are to be adjusted.
2. Loosen the locknut (jam nut) on the tappet screw, and insert a screwdriver in the slot of the screw.
3. Insert a feeler gage of the proper thickness between the tappet bearing and the end of the valve stem.



75.78

Figure 4-8.—Adjusting valve clearance.

4. Tighten the tappet screw (fig. 4-8) until the feeler gage will just slide freely between the bearing and the valve.
5. Tighten the jam nut and check the clearance. The jam nut has a tendency to increase the clearance when tightened; therefore, ALWAYS check the clearance after you tighten the jam nut.

The procedure outlined above is a preliminary, or "cold engine" check. Clearance should be checked and readjusted, if necessary, after the engine has been in operation for a short time and has reached the normal operating temperature. The manufacturer's technical manual will give the recommended valve clearances for a specific make and model of engine and will indicate whether the clearances given apply to "cold" or "hot" engines.

CAM FOLLOWERS AND LASH ADJUSTERS

In the valve actuating mechanism, cam followers change the rotary motion of the

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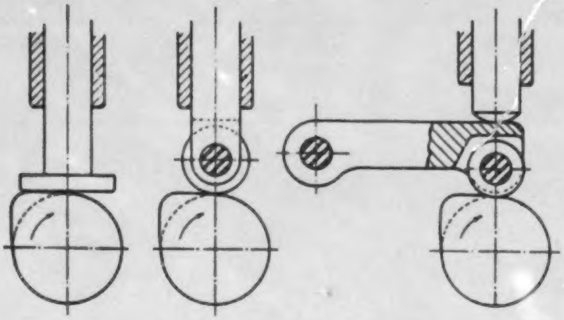


75.79

Figure 4-9.—Cam followers.

camshaft to reciprocating motion in order to open the valves. Cam followers ride the flat of the cam and are raised, as the cam rotates, by the high side of the cam and lowered by tension from the valve spring. Three types of cam followers used in internal-combustion engines are illustrated in figure 4-9.

Regardless of the type of cam follower, wear is the most common trouble. Worn rollers will usually develop holes or pit marks in the roller surfaces. The mushroom type may develop a shallow channel when the cam follower fails to revolve and the cams wipe the same surface each time the camshaft revolves.

Normal use will cause surface disintegration, usually due to fatigue of the hardened surfaces. The condition is aggravated by abrasive particles. Nicks and dents on rollers will also start disintegration.

You must make constant checks for defective rollers or surfaces and for nicks, scratches, or dents in the camshaft. Whenever you find a defective cam follower, you should replace it. In roller type cam followers, you must replace a worn cam follower body and guide or roller needle bearings (if used).

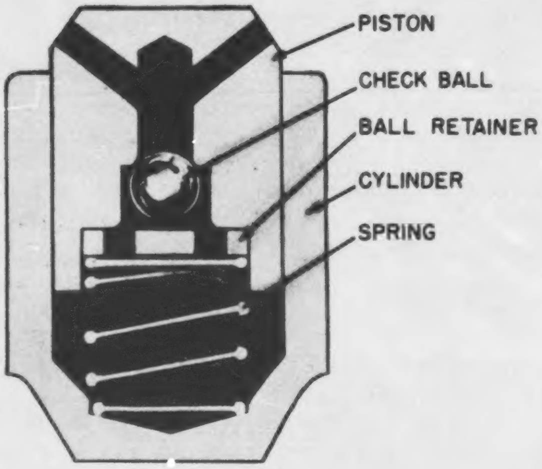
Hydraulic valve lifters or lash adjusters control valve gear clearances or lash. They may be installed on push rods, rocker arms, or on the cam follower. Figure 4-10 shows a larger sectional view of the hydraulic lash adjuster illustrated in figure 4-7.

Hydraulic valve lifters (also called valve adjusters) are usually adjusted with their internal parts in compression or with "zero valve clearance." Follow the manufacturer's technical manuals closely to obtain normal life of valves and operating gear.

Hydraulic lash adjusters may vary in design but generally consist of such basic parts as a cylinder, a piston or plunger, a ball check valve, and a spring. As precision parts, hydraulic valve lifters or adjusters require special care in handling. and they must be kept exceptionally clean. Abrasive materials must be prevented from entering a hydraulic lash adjuster if they are to perform their function satisfactorily.

Defective or poorly operating valve adjusters allow clearance or lash in the valve gear. Noisy operation of a lash adjuster indicates that there is insufficient oil in the cylinder of the unit. When a noisy lash adjuster is discovered and the oil supply or pressure is not the source of trouble, the unit should be removed from the engine and disassembled in accordance with the manufacturer's instructions.

Since the parts of lash adjusters are not interchangeable, only one unit should be



75.80X

Figure 4-10.—Hydraulic lash adjuster.

disassembled at a time. Check for resinous deposits, abrasive particles, a stuck ball check valve, a scored check valve seat, and excessive leakage. All parts of the hydraulic lash adjuster should be carefully washed in kerosene or diesel fuels. Such parts as the cam follower body, plunger or piston, and hydraulic cylinder should be checked for proper fit.

PISTON AND ROD ASSEMBLIES

Piston and rod assemblies will include a piston, piston rings, piston pin, and connecting rod. These units and their functions in engine operation are discussed separately in the following sections.

PISTONS

As one of the principal parts in the power-transmitting assembly, the piston must be so designed and must be made of such materials that it can withstand the extreme heat and pressure of combustion. Pistons must also be light enough to keep inertia loads on related parts to a minimum. The piston aids in sealing the cylinder to prevent the escape of gas; it also transmits some of the heat through the piston rings to the cylinder wall.

Pistons have been constructed of a variety of metals–cast iron, nickel cast iron, steel alloy, and aluminum alloy. Pistons of cast iron and aluminum are most commonly used at the present time. Cast iron gives longer service with little wear; it can be fitted to closer clearances, and it distorts less than aluminum. Lighter weight and higher conductivity are the principal advantages of aluminum.

Cast iron is generally associated with the pistons of slow-speed engines. However, cast iron is used for the pistons of some high-speed engines, in which case, the piston walls are of very thin construction and require additional cooling.

Pistons perform a number of functions. A piston, in addition to transmitting the force of combustion to the connecting rod and conducting the heat of combustion to the cylinder wall, may serve as a valve in opening and closing the ports of a 2-stroke cycle engine. Other functions of a piston and its parts are discussed in the following paragraphs.

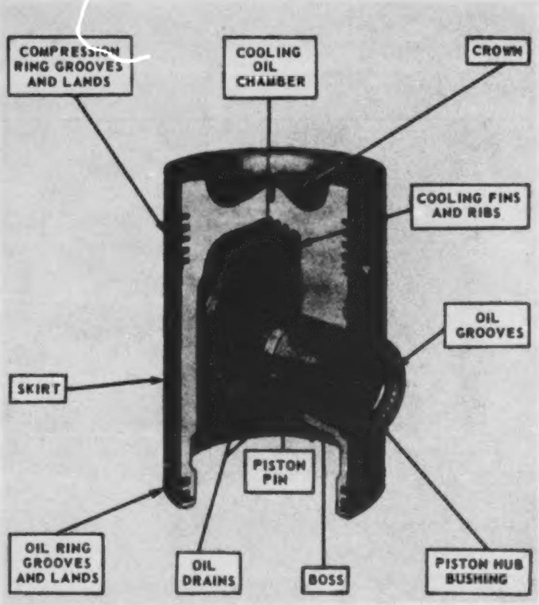


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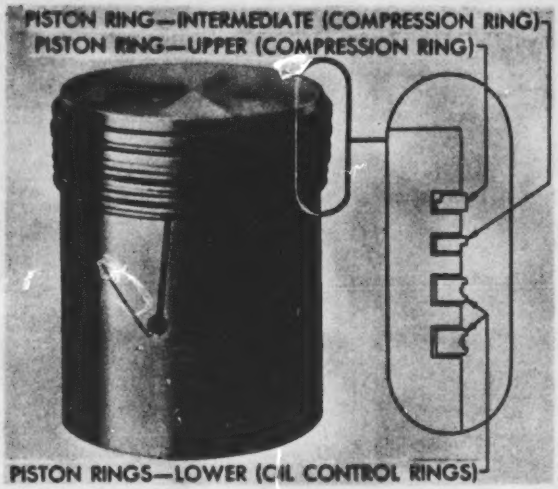
Figure 4-11.–Piston nomenclature for trunk-type piston.

There are two distinct types of pistons: the trunk type and the crosshead type.

Trunk Type Pistons

Variations in the design of trunk type pistons can be seen in figures 4-11 and 4-12.

The CROWN, or head, of a piston acts as the moving surface that changes the volume of the cylinder's content (compression), removes gases from the cylinder (exhaust), and transmits the force of combustion (power). Generally, the crown end of a piston is slightly smaller in diameter than the skirt end. The resulting slight taper allows for expansion of the metal at the combustion end. Even though slight, the taper is sufficient so that, at normal operating


PISTON RING—INTERMEDIATE (COMPRESSION RING)
PISTON RING—UPPER (COMPRESSION RING)
PISTON RINGS—LOWER (OIL CONTROL RINGS)

75.50

Figure 4-12.--Trunk-type piston.

temperatures, the diameter of the piston is the same throughout.

Manufacturers have produced a variety of crown designs—truncated, cone, recessed, dome or convex, concave or cup, and flat. Piston crowns of concave design are common in marine engines used by the Navy; however, other types may be encountered. An advantage of the concave shape is that it assists in creating air turbulence, which mixes the fuel with air during the last part of compression in diesel engines. Some concave type pistons have recesses in the rim to allow room for parts which protrude into the combustion space. Examples of such parts are the exhaust and intake valves, the air starting valve, and the injection nozzle. In some 2-stroke cycle engines, piston crowns are shaped with irregular surfaces which deflect and direct the flow of gases. Two of the piston crowns just mentioned are shown in figures 4-11 and 4-12.

The SKIRT of a trunk type piston receives the side thrust created by the movement of the crank and connecting rod. In turn, the piston transmits the thrust to the cylinder wall. In addition to receiving thrust, the skirt aids in keeping the piston in proper alignment within the cylinder.

Piston skirts may be one of three types—plain or smooth, slotted or split, or knurled. Some plain skirt pistons have a smooth bearing surface throughout the length of the piston. In others, the diameter of the skirt in the vicinity of the bosses is slightly less than that of the rest of the piston. Pistons with slotted skirts (fig. 4-12) permit the skirt to expand without increasing the piston diameter at heavy sections. The knurled skirt contains knurls (small beads or diamonds) on the metal surface. One advantage of pistons of the knurled type is longer service because of better lubrication from the greater amount of oil carried by the knurls.

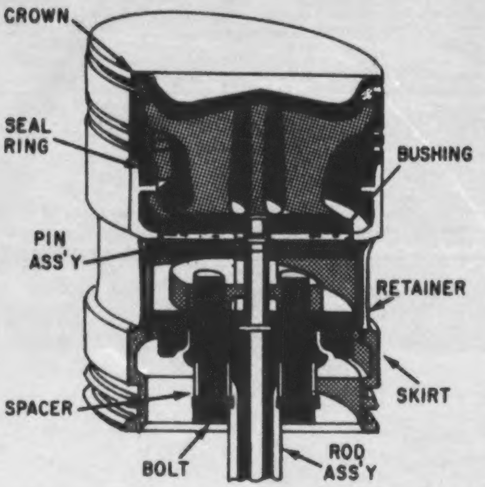
Most trunk-type pistons are of one-piece construction. Some trunk pistons are made of two parts and two metals; the trunk or skirt is made of cast iron or an alloy, and the crown or head is made of steel. In some pistons of this type construction the crown is fitted to the trunk with a ground joint, while in others the parts are welded together.

Without GROOVES and LANDS, the piston rings cannot be properly spaced or held in position. The number of grooves and lands on a piston will vary considerably, depending on such factors as the size and the type of the piston. (See fig. 4-11 and 4-12.)

Some pistons have OIL DRAINS (small holes) in the bottom of some of the grooves (fig. 4-11); some pistons have oil drains in the skirt of the piston. These holes serve as oil returns, permitting lubricating oil from the cylinder wall to pass through the piston into the crankcase.

Generally, the BOSSES (hubs) of a piston are heavily reinforced openings in the piston skirt. Some bosses are a part of an insert which is secured to the inside of the piston. The principal function of the bosses is to serve as mounting places for the bushings or bearings which support the piston pin. They provide a means of attaching the connecting rod to the piston. In some pistons the bosses serve as the pin bearings. Generally, the diameter of the piston at the bosses is slightly less than the diameter of the rest of the piston to compensate for the expansion of the extra metal in the bosses. (See fig. 4-11.)

Because of the intense heat generated in the combustion chamber, adequate COOLING must



75.240
Figure 4-13.–Typical Cross-Head Piston and Connecting Rod Assembly.

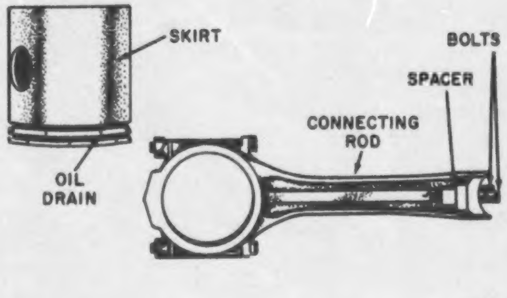
be provided. The heat transmitted through the rings (approximately 30% of the heat absorbed by the piston) to the cylinder wall is not sufficient in many engines to keep the unit cooled within operating limits. Most pistons have fins or ribs and struts as internal parts. (See fig. 4-11.) The additional surfaces of these parts help to dissipate heat; much of the heat is carried away by oil which may be pump-force, splashed, or thrown by centrifugal force into the piston assembly. Oil is the principal means of cooling most piston assemblies. Intake air is also used in cooling hot engine parts. In order to exhaust or scavenge a cylinder of burned gases and cool the engine parts, the intake and exhaust valves or ports are so timed that both are open for a short time at the end of the exhaust stroke, allowing the intake air to enter the cylinder, clean out the hot gases, and, at the same time, cool the parts.

Crosshead Pistons

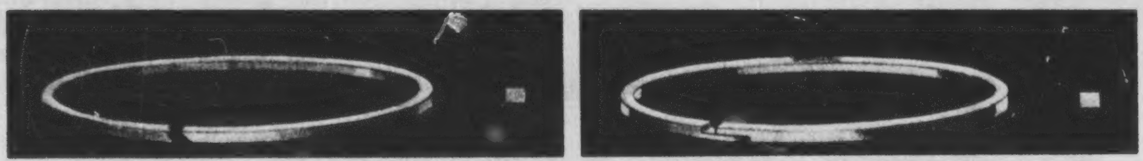
A type of crosshead piston is being introduced for use in certain engines (fig. 4-13 and 4-14). The crosshead pistons used in older designs of engines were used primarily to absorb side thrust resulting from extremely long strokes and horsepower ratings in excess of 150 hp per cylinder. The modern crosshead piston is a two-piece unit with a crown that can withstand the high heat and pressure of a turbocharged engine and a skirt specifically designed to absorb side thrust.

The crown and skirt are held together by the piston pin. The downward load on the crown pushes directly on the pin through a large slipper bearing. The separate skirt has less thermal distortion than the crown piece and is free of downward thrust loads. It specifically guides the piston in the cylinder, takes up side thrust, and carries the oil scraper rings. The crown has the compression rings. Since it is separate, it takes only a slight amount of side thrust and is not forced to slide sideways under the compression rings when they are pressed hard against the bottoms of their grooves by combustion gas pressure. Lubricating oil is fed upward by pressure to cool the piston crown.

The unit shown in figures 4-13 and 4-14 replaces, or is a retrofit for, a trunk type piston. It has three rings in the crown while the trunk piston has four compression rings. When an engine is being retrofitted, all trunk pistons

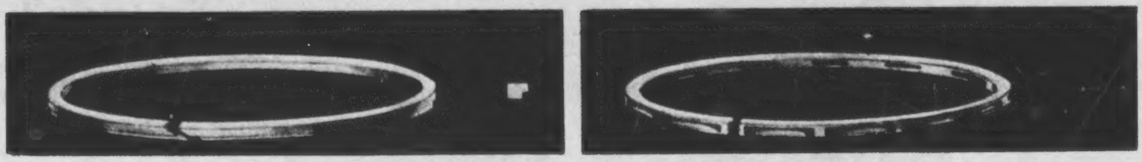


75.241
Figure 4-14.--Typical Cross-Head Piston and Connecting Rod Components.



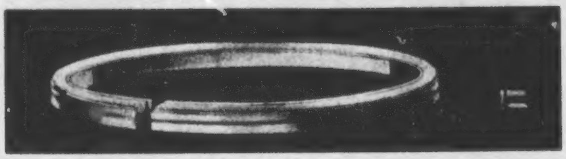
A-DIAGONALLY CUT COMPRESSION RING

B-LAP-JOINT COMPRESSION RING



C-OIL RING

D-SLOTTED OIL RING



E-THREE-PIECE OIL RING

75.51

Figure 4-15.—Types of piston rings.

should be replaced. A mixture of trunk and crosshead pistons should not be used in the same engine. In addition, if the type of piston is changed, several other engine parts and operating parameters must be altered.

PISTON RINGS

Piston rings are particularly vital to engine operation in that they must effectively perform three functions: seal the cylinder, distribute and control lubricating oil on the cylinder wall, and transfer heat from the piston to the cylinder wall. All rings on a piston perform the latter function, but two general types of rings—compression and oil—are required to perform the first two functions. There are many variations in the design of compression and oil rings. Some variations are illustrated in figure 4-15.

The number of rings on a piston will vary with the type and size of the piston.

The location of rings also varies considerably (fig. 4-11 and 4-13). Obviously, the compression rings are located toward the crown or combustion end of the piston. The ring closest to the crown is sometimes referred to as the "firing" ring. In some pistons, both compression and oil rings are located toward the crown, "above" the pin bosses. In other pistons, the compression rings and one or two oil rings are above the bosses with one or two oil rings "below" the bosses. (The terms "above" and "below" adequately identify ring location when the crown of the piston is at the top, as in engines of the vertical in-line type or even some V-types. When these terms may lead to confusion, such as when referring to ring location on the upper pistons of opposed-piston engines, piston ring location can be more accurately identified by referring to the "crown or combustion end" and the "skirt or crankshaft end" of the piston.)

Compression Rings

The principal function of compression rings is to seal the cylinder and combustion space so that the gases within the space cannot escape until they have performed their function. Some oil is carried with the compression rings as they travel up and down the cylinder.

Most compression rings are made of gray cast-iron; however, some types have special facings, such as bronze, inserted in a slot cut circumferentially around the ring or a treated surface. Rings with the bronze inserts are sometimes called "gold seal" rings, while those with special facings are referred to as "bimetal" rings. The bimetal ring is two layers of metal bonded together, the inner layer being steel and the outer being cast iron.

Compression rings come with a variety of cross sections; however, the rectangular cross section is the most common. Since piston rings contribute as much as any other one thing toward maintaining pressure in a cylinder, they must possess sufficient elasticity to press uniformly against the cylinder walls. The diameter of the ring, before installation, is slightly larger than the cylinder bore. Because of the joint, the ring can be compressed to enter the cylinder. The tension created when the ring is compressed and placed in a cylinder causes the ring to expand and produce a pressure against the cylinder wall. The pressure exerted by rings closest to the combustion space is increased by the action of the confined gases during compression and combustion. The gases enter behind the top ring, through the clearance between the ring and groove, and force the ring up against the cylinder and down against the bottom of the groove. The gas pressure on the second ring and each successive compression ring is progressively lessened since the gas reaching these rings is limited to that passing through the gap of the firing ring.

When a piston assembly is disassembled, you can look at the compression rings and tell whether they have been functioning properly. If a ring has been working properly, the face (surface bearing against the cylinder wall) and the bottom of the ring will be bright and shiny because of contact with the cylinder wall and the groove. The top and back (inside surface) of the ring will be black, since they are exposed to the hot combustion gases. The exposed sides and corresponding parts of the ring groove may be covered with deposits of carbon which must be removed during overhaul. Black areas on sealing surfaces indicate that hot gases have been escaping.

Under normal operating conditions, with engine parts functioning properly, there will be very little leakage of gas because of the excellent sealing of the piston rings. The oil that prevents metal-to-metal contact between the rings and cylinder wall also helps, to a degree, in making the seal. When a proper seal is established, the only point at which gas can leak is through the piston ring gap.

The gap of a piston ring is so small, compared to the total circumference of the ring, that the amount of leakage is negligible when rings are functioning properly. In modern, high-speed engines, gas pressure is not applied enough to the rings to cause any appreciable leakage through the joints. Leakage can be held to a minimum if the rings are placed so that the joints of successive rings are on alternate sides of the piston. Most pistons have no means of preventing the rings from shifting or turning around in the grooves; however, some manufacturers provide metal pins or dowels to prevent rings from shifting around in the grooves.

Oil Rings

Although oil rings come in a large variety of designs, they must all do two things. Oil rings must distribute enough oil to the cylinder wall to prevent metal-to-metal contact, and they must control the amount of oil distributed.

Without an adequate oil film between the rings and the cylinder, undue friction occurs, resulting in excessive wear of the rings and the cylinder wall. On the other hand, too much oil is as undesirable as not enough oil. If too much oil is distributed by the rings, the oil may reach the combustion space and burn, wasting oil and causing smoky exhaust and excessive carbon deposits in the cylinder. Such carbon deposits may cause the rings to stick in their grooves.

Sticking rings generally lead to a poor gas seal. Thus, oil rings provide an important function in proper control and proper distribution of the lubricating oil. Oil control and distribution in the cylinders of an engine are controlled by rings of various designs. Three types of these rings are shown in parts C, D, and E of figure 4-15.

Different manufacturers use a variety of terms in their technical manuals to identify the oil rings of an engine—such terms as oil control, oil scraper, oil wiper, oil cutter, oil drain, oil regulating, etc. Regardless of the identifying terms used, all such rings are designed to control and distribute lubricating oil within the cylinder of an engine.

If a distinction is to be made between types of oil rings, perhaps the terms "oil control" and "oil scraper" should be used. When this distinction is made, the oil control rings are those oil rings closest to the compression rings, while the oil scraper or wiper rings are those farthest from the combustion end of the piston. The oil control rings prevent excessive amounts of oil from flowing to the compression rings and entering the combustion space. The oil scraper rings regulate the amount of oil passing between the piston skirt and cylinder wall by wiping off the excess oil thrown into the cylinder bore by the crankshaft and connecting rod. The oil rings must distribute enough oil on the upper part of the cylinder wall to properly lubricate the piston and the compression rings.

In general, manufacturers identify oil rings by the term which best describes the function performed by the rings of their design. These terms, as well as design, vary with respect to location on any given piston. For example, a GM 6-71 piston has two "oil control" rings placed on the skirt below the pin. Both rings are identical, each consisting of three pieces (two rings and an expander). The ring illustrated in part E of figure 4-15 is representative of a 3-piece oil ring. In rings of this type, the two "scraping" pieces have very narrow faces bearing on the cylinder wall, which permit the ring assembly to rapidly conform to the shape of the cylinder wall. Since the ring tension is concentrated on a small area, the rings will cut through the oil film easily and remove the excess oil. The bevel on the upper edge of each ring face causes the ring to ride over the oil film as the piston moves toward TDC, but as the piston moves downward for intake and power, the sharp, hook-like lower edge of each ring scrapes or wipes the oil from the cylinder wall.

Another example of differences in terminology and location is found in the FM 38D8 1/8. A piston in this type of engine has three oil rings all located on the skirt end. The two nearest the crankshaft end of the piston are called oil "drain" rings, while the ring nearest the pin bosses is referred to as the "scraper." The drain rings are slotted to permit oil to pass through the ring and to continue on through the holes drilled in the ring grooves. Part D of figure 4-15 shows one type of slotted oil ring.

Replacement of Piston Rings

While you may be able to free stuck rings and make them serviceable, you must replace excessively worn or broken rings with new ones. The installation of a new set of rings in an engine requires great care. Most of the damage that is done occurs when the rings are being placed in the grooves of a piston or when the piston is being inserted in the cylinder bore.

You must be very careful when removing the piston and connecting rod from the cylinder. In most engines, you should not remove a piston from a cylinder until you have scraped the cylinder surface above the ring travel area. In addition to removing all carbon, you must remove the lip of any appreciable ridge before removing the piston. Do not remove a ridge by grinding, as this will allow small abrasive particles from the stone to enter the engine. Use a metal scraper and place a cloth in the cylinder to catch all metal cuttings. You can usually scrape enough from the lip of a cylinder to allow the piston assembly to slide out of the liner. After removing the piston, you can make a more detailed inspection of the ridge.

Finish scraping the remaining ridge, but be careful not to go too deep. Finish the surface with a handstone. For large ridges, you may need to remove the liner and use a small power grinder.

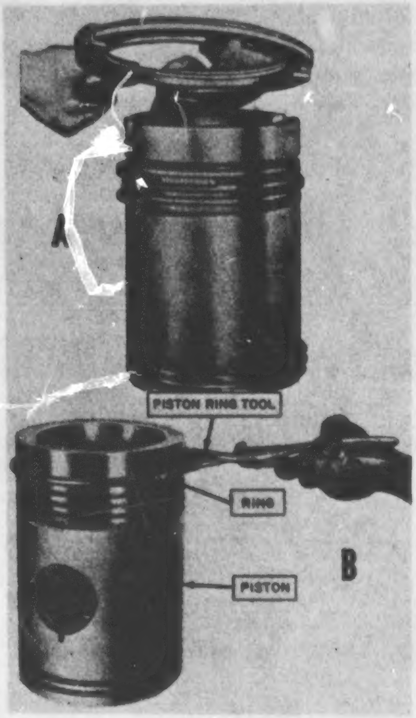


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Figure 4-16.–Piston ring tools used for removal or installation.

After removing the piston and connecting rod, check the condition and wear of the piston pin bushing, both in the piston and in the connecting rod.

The best way to remove and install piston rings is with a tool similar to that shown in figure 4-16. These tools generally have a device that limits the amount the ring can be spread and prevents the rings from being deformed or broken.

A ring that is securely stuck in the groove will require additional work. You may need to soak the piston overnight in an approved cleaning solvent or in diesel oil. If soaking does not free the ring, you must drive it out with a brass drift. The end of the drift should be shaped and ground in a manner that permits its use without damage to the lands.

After removing the rings, thoroughly clean the piston with special attention to the ring grooves. (Diesel oil or kerosene are satisfactory cleaning agents.) In addition, you may need to clean excessive deposits from the oil return holes in the bottom of the oil control ring grooves with a twist drill of a diameter corresponding to the original size of the holes.

Make another complete inspection after cleaning the piston. Check all parts for any defects which could require replacement of the piston. Give particular attention to the ring grooves, especially if the pistons have been in service for a long period of time. A certain amount of enlargement of the width of the grooves is normal, and SHOULDERING of the groove may occur. Shouldering as illustrated in figure 4-17, results from the "hammering out" motion of the rings. The radial depth of thickness of the ring is much less than the groove depth, and, while the ring wears away an amount of metal corresponding to its own width, the metal at the bottom of the groove remains unchanged. Shouldering usually requires replacement of the piston since the shoulders prevent the proper fitting of new rings.

After determining that a piston is serviceable, inspect the rings carefully to determine whether they can be reused. If they do not meet specifications, you must install new rings.

When installing rings, measure the gap with a feeler gage. To measure the gap, place the new

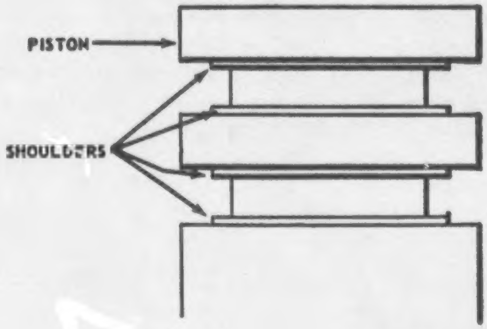

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Figure 4-17.–Ring groove shoulder due to wear.

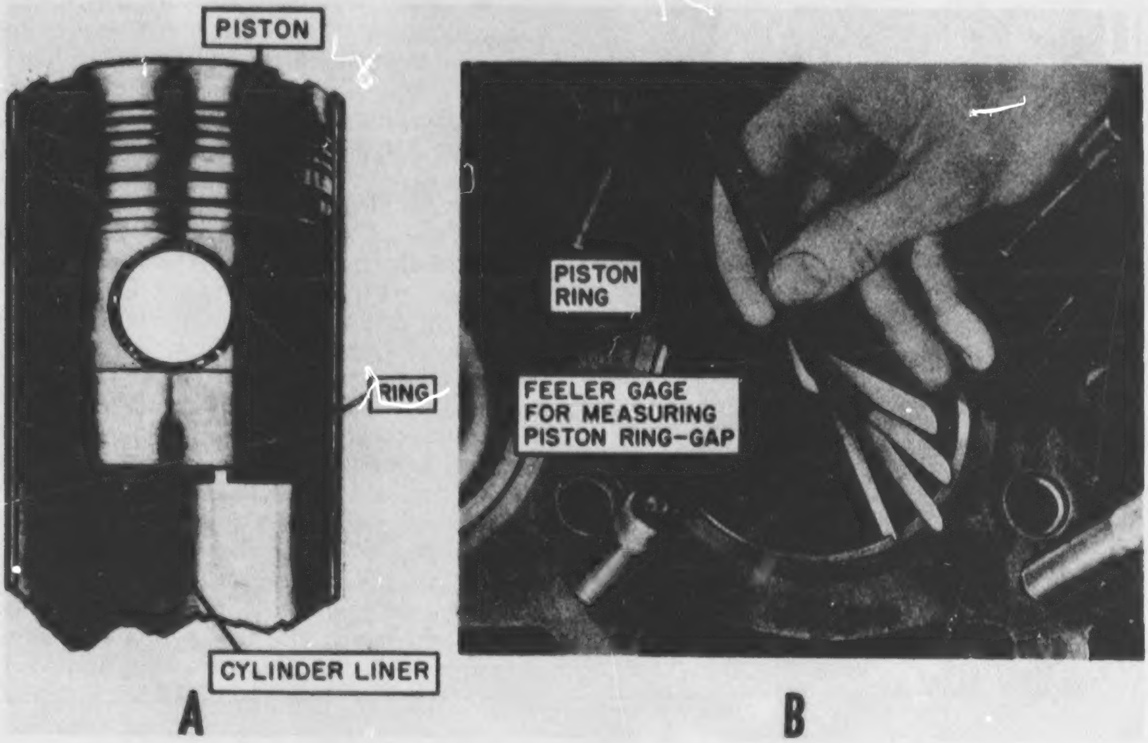

Figure 4-18.--A. Leveling a piston ring. B. Measuring ring gap clearance in cylinder bore.

rings inside the cylinder liner (fig. 4-18A) or in a ring gage. When the gap is measured with the ring in the liner (fig. 4-18B), two measurements are necessary—one just below the upper limit of ring travel, and the other within the lower limit of travel. These measurements are necessary because the liner may have a slight amount of taper caused by wear. Ring gap must be within the limits specified in the manufacturer's technical manual. If the gap of a new ring is less than specified, you will need to file the ends of the ring with a straight-cut mill file to obtain the proper gap. If the gap is more than specified, you will need to install oversized rings.

To measure the ring gap of used rings, hold the rings in place on the piston with a ring compressing tool (fig. 4-19). When measuring the ring gap with the ring on the piston, you must first measure the piston for wear and out-of-roundness.

After determining the proper gap clearance, you can reinstall the piston pin and connecting rod. During reassembly and installation of a piston and connecting rod assembly, be sure that all parts are well lubricated. Install the rings on the piston with tools similar to those used for removal. When installing piston rings, spread them as little as possible to avoid breaking the rings. Insert the lowest ring first. When all the rings have been installed, check the ring-to-land clearance. (See fig. 4-20). If the clearance is too small, the ring may bind or seize, allowing improper sealing and blowby to occur. If the clearance is excessive, the ring may flutter and break the piston land or rings.

After all the rings have been properly installed, coat the entire assembly with oil, then

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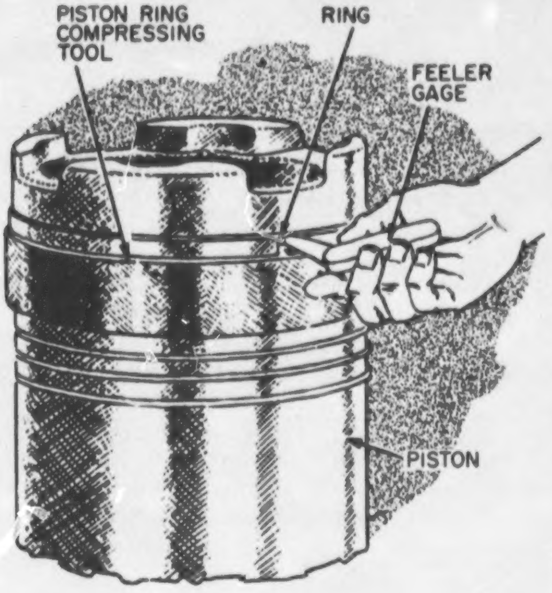

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Figure 4-19.–Checking ring gap clearance.

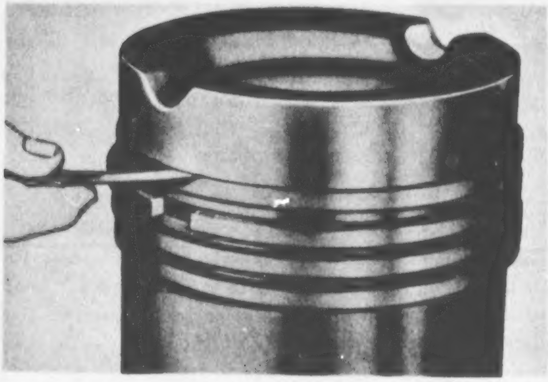

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Figure 4-20.–Checking ring groove side clearance.

insert it in the cylinder bore. Position the rings so that the gap of each successive ring is on an alternate side and the gaps are in line with the piston pin bosses. On large engines, use a chain fall to hold the piston assembly in position as it is being lowered into the cylinder (See fig. 4-21).

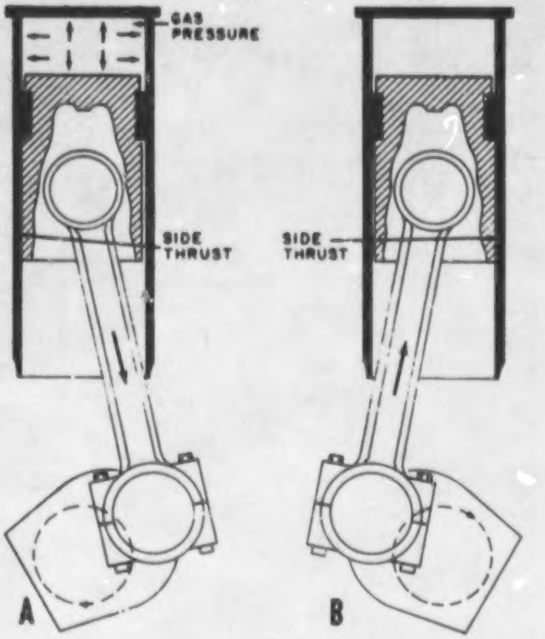
PISTON
RING COMPRESSING
TOOL

75.56
Figure 4-21.–Installing a piston in a cylinder bore with funnel-type ring compressor.

When a piston is being inserted into a cylinder, the piston rings must be compressed evenly. Special funnel-type tools, similar to the one shown in figure 4-21, are usually provided for this purpose. Another type of ring compressing tool is a steel band that can be placed around the ring and tightened.

PISTON PINS AND PISTON BEARINGS

In trunk-type piston assemblies, the only connection between the piston and the connecting rod is the pin (sometimes referred to as the wrist pin) and its bearings. These parts must be of especially strong construction because the power developed in the cylinder is transmitted from the piston through the pin to



75.57
Figure 4-22.—Side-thrust trunk piston, single-acting engine.

the connecting rod. The pin is the pivot point where the straight-line, or reciprocating motion, of the piston changes to the reciprocating and rotating motion of the connecting rod. Thus, the pin is subjected to two principal forces—the forces created by combustion and the side thrust created by the change in direction of motion. Before discussing the pin further, let us consider the side thrust which occurs in a single-acting engine equipped with trunk-type pistons (See fig. 4-22).

Side thrust is exerted at all points during a stroke of a trunk-type piston, except at TDC and BDC. The side thrust is absorbed by the cylinder wall. Thrust occurs first on one side of the cylinder and then on the other, depending on the position of the piston and the rod and the direction of rotation of the crankshaft. In figure 4-22A, gas pressure is forcing the piston downward (power). Since the crankshaft is rotating clockwise, the force of combustion and the resistance of the driven parts tend to push the piston to the left. The resulting side thrust is exerted on the cylinder wall. If the crankshaft were rotating counterclockwise, the situation would be reversed.

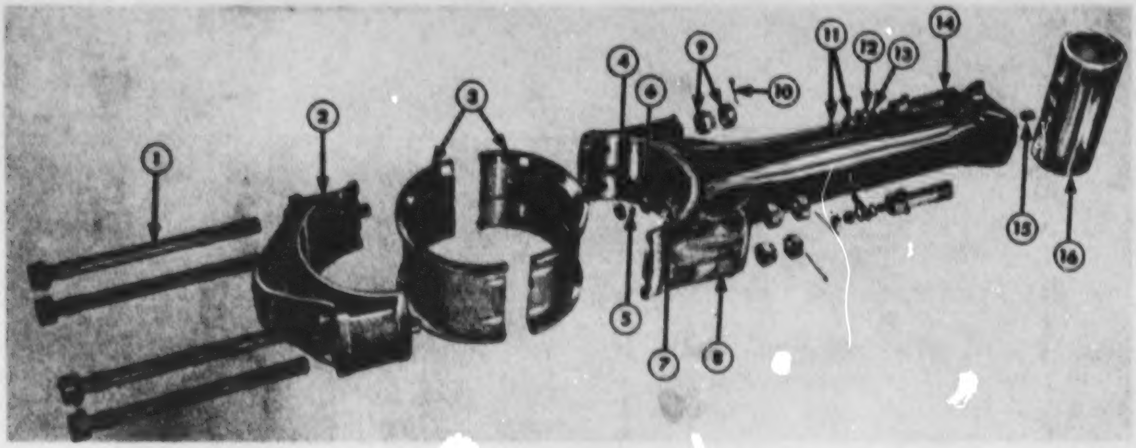
In figure 4-22B, the piston is being pushed upward (compression) by the crankshaft and connecting rod. This causes the side thrust to be exerted on the opposite side of the cylinder. Thus, the side thrust alternates from side to side as the piston moves up and down. Side thrust in an engine cylinder makes proper lubrication and correct clearance essential. Without an oil film between the piston and the cylinder wall, metal-to-metal contact occurs and results in excessive wear. If the clearance between the piston and cylinder wall is excessive, a pounding noise, called PISTON SLAP, will occur as the thrust alternates from side to side.

Types of Piston Pins

Pins are usually hollow and made of alloy steel, machined, hardened, and precision-ground and lapped to fit the bearings. Their construction provides maximum strength with minimum weight. Some pins are chromium-plated to increase the wearing qualities. The pins are lubricated by splash from the crankcase or by oil forced through drilled passages in the connecting rods.

You must securely position piston pins so that they do not protrude beyond the surface of the piston or have excessive end-to-end motion. Otherwise, the pin will tend to damage the cylinder wall. Piston pins may be secured in the piston rod assembly in one of three ways: (1) rigidly fastened into the piston bosses, (2) clamped to the end of the rod, or (3) free to rotate in both piston and rod. When piston pins are secured by these methods, the pins are identified as: (1) stationary (fixed), (2) semifloating, and (3) full-floating, respectively.

The STATIONARY pin is secured to the piston at the bosses, and the connecting rod oscillates on the pin. Since all movement is by the connecting rod, uneven wear may occur on the contacting surfaces in this type of installation.



75.58

Figure 4-23.—Connecting rod assembly with semifloating piston pin.

SEMIFLOATING type pins are secured in the middle to the connecting rod. (See fig. 4-23.) The ends of the pin are free to move in the piston pin bearings in the bosses.

FULL-FLOATING pins are not secured to either the piston or the connecting rod. Pins of this type may be held in place by caps, plugs, and snap rings, or spring clips which are fitted in the bosses. The securing devices for a full-floating pin permit the pin to rotate in both the rod and piston pin bosses. The full-floating piston pin is the most common of the three types.

Types of Piston Pin Bearings

The bearings used in connection with piston pins are of three types: the integral bearing, the sleeve bearing or bushing, and the needle-type roller bearing. These bearings may be further identified according to location—the piston boss piston pin bearings and the connecting rod piston bearings.

The bearings or bushings are made of bronze or similar material. Since the bushing material is a relatively hard-bearing metal, surface-hardened piston pins are required. The bore of the bushing is accurately ground in line for the close fit of the piston pin. Most bushings have a number of small grooves cut in their bore for lubrication purposes (fig. 4-11). Some sleeve bushings have a press fit, while others are "cold shrunk" into the bosses.

Bearings of the sleeve bushing type for both the bosses and the connecting rod are shown in figure 4-24. Note that the bosses are a part of an insert.

If the piston pin is secured in the bosses (stationary) of the piston or if it floats (full-floating) in both the connecting rod and piston, the piston end of the rod may be fitted with a sleeve bushing. Pistons fitted with semifloating pins (fig. 4-23) require no bearing at the rod.

Sleeve bushings used in the piston end of connecting rods are similar in design to those used in piston bosses. (See fig. 4-11). Generally, bronze makes up the bearing surface. Some bearing surfaces are backed with a case-hardened steel sleeve, and the bushing has a shrink fit in the rod bore. In other bushings, the bushing fit is such that a gradual rotation (creep) takes place in the eye of the connecting rod. In another variation of the sleeve-type bushing, a cast bronze lining is pressed into a steel bushing

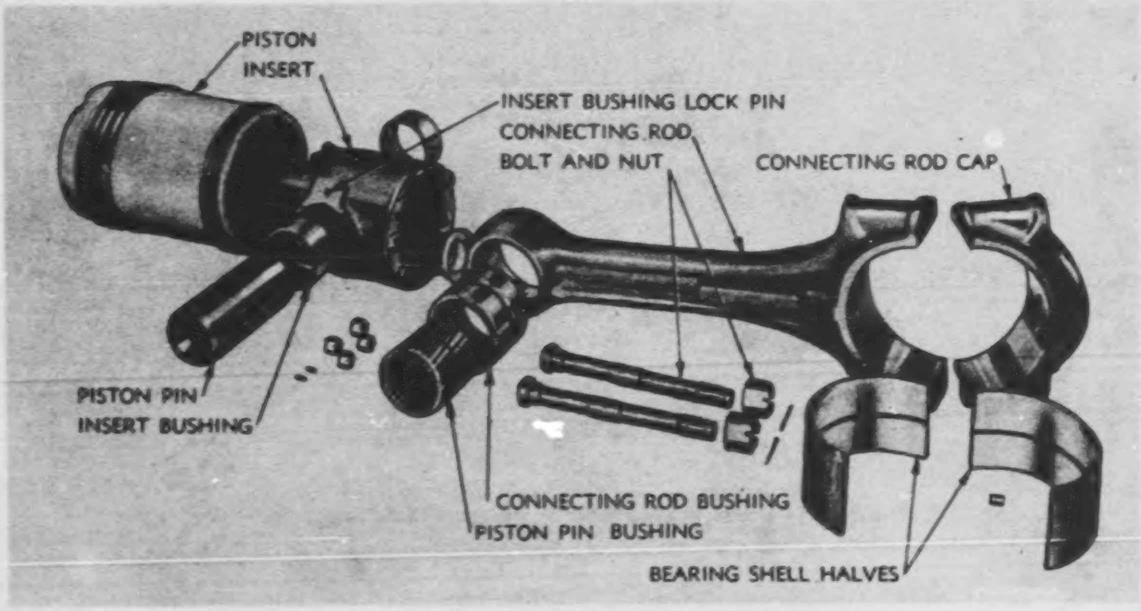


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Figure 4-24.—Piston and rod assembly with sleeve bushing type bearings.

in the connecting rod. In some engines that use full-floating piston pins, the steel-backed bronze bushing rotates freely inside the piston end of the connecting rod.

Care of Pins and Bearings

Every time you remove a piston assembly from an engine, inspect it for wear. Measure the piston pins and bushings with a micrometer, as shown in figure 4-25 to determine whether wear is excessive. Do NOT measure areas that do not make contact. Such areas include those between the connecting rod and piston bosses and areas under the oil holes and grooves.

You can press bushings out of the rod with a mandrel and an arbor press or with special tools as shown in figure 4-26. You can also remove bushings by first shrinking them with dry ice. Dry ice will also make it easier to insert the new bearing.

When you insert new bushings, be sure that the bore into which they are pressed is clean and that the oil holes in the bushing and the oil passages in the rod are aligned. To obtain proper clearance, sometimes you will need to ream a piston pin bushing after it has been installed. Figure 4-27 shows equipment used to ream a bushing. After installing a new bushing, you should check the alignment of the rod with equipment such as illustrated in figure 4-28. Be sure to check the manufacturer's technical manual for details concerning clearances and alignment procedures.

CONNECTING RODS

The connecting rod is the connecting link between the piston and crankshaft. The rod changes the reciprocating motion of the piston to the rotating motion of the crankshaft so that the forces of combustion can be transmitted to the crankshaft. In general, the type of

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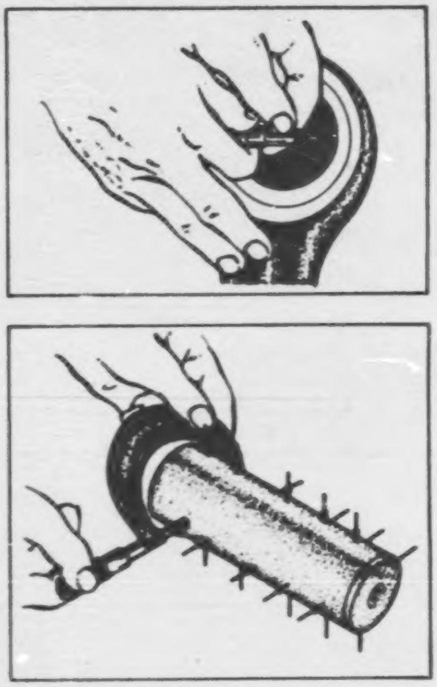

75.61
Figure 4-25.–Measuring a piston pin and piston bushing for wear.

connecting rod used in an engine depends on the cylinder arrangement and the type of engine.

Several types of connecting rods have been designed; however, only two (the conventional rod and the fork and blade rod) of those likely to be found in marine engines used by the Navy are discussed here.

Conventional Rods

The conventional type rod is sometimes referred to as the "normal" or "standard" rod because of its extensive use by many manufacturers and its similarity to the rods used in many automobiles. Examples of the conventional rod are shown in figures 4-23 and 4-24. The rods illustrated are typical of those used in engines of the single-acting, in-line type. Rods of this type are also used in opposed-piston engines and in some V-type engines. When used in V-type engines, two rods are mounted on a single crankpin. The two cylinders served are offset so that the rods can be operated side-by-side.

Rods are generally made of drop forged heat-treated carbon steel (alloy steel forging). Most rods have an "I" or "H" shaped cross section which provides maximum strength with minimum weight. The bore (hub, eye) at the piston end of the rod is generally forged as an integral part of the rod (fig. 4-24); however, the use of semifloating piston pins (fig. 4-23) eliminates the need for the bore. The bore at the crankshaft end is formed by two parts, one an integral part of the rod and the other a removable CAP. (See fig. 4-23 and 4-24.) Rods are generally drilled or bored to provide an oil passage to the piston end of the rod.

The bore at the crankshaft end of a conventional rod is generally fitted with a precision bearing of the shell type. (See fig. 4-23 and 4-24.) In design and materials, rod bearings are similar to the main journal bearings which are discussed in connection with crankshafts later in this chapter.

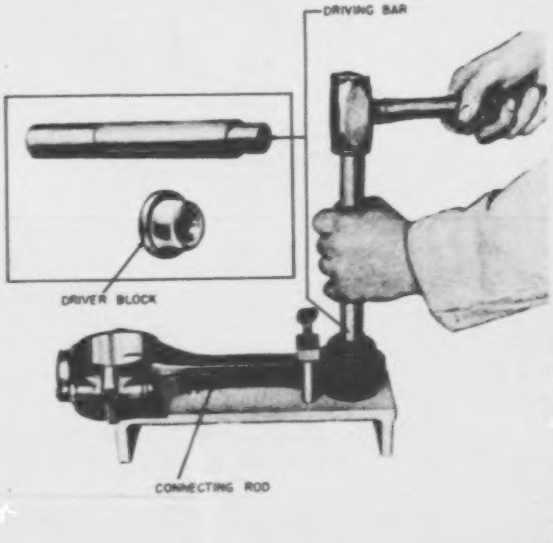

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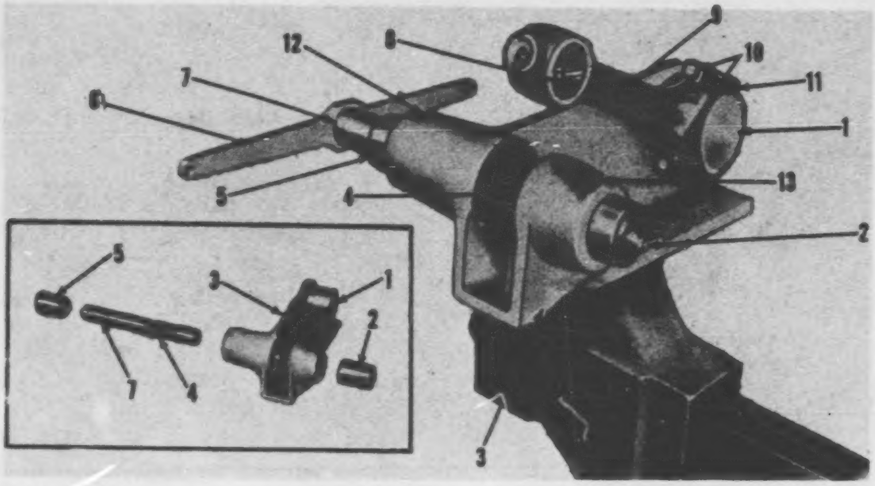
Figure 4-26.–Removing or installing a piston pin bushing.



1. Arbor.
2. Guide Bushing—Rear.
3. Body.
4. Flutes (Cutting Edges).
5. Guide Bushing—Front.
6. Handle.
7. Reamer.
8. Piston Pin Connecting Rod Bushing.
9. Connecting Rod.
10. Connecting Rod Bolt.
11. Connecting Rod Cap.
12. Front Guide Boss.
13. Rear Guide Boss.

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Figure 4-27.—Reaming equipment.

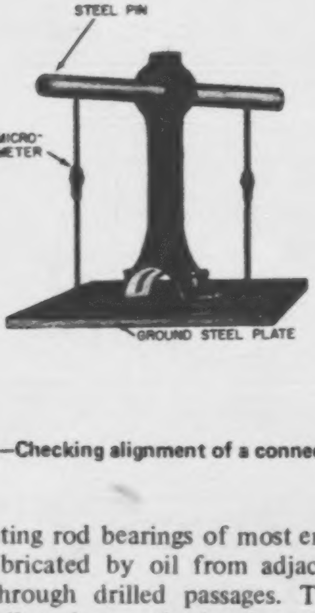

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Figure 4-28.—Checking alignment of a connecting rod.

Connecting rod bearings of most engines are pressure lubricated by oil from adjacent main bearings, through drilled passages. The oil is evenly distributed over the bearing surfaces by oil grooves in the shells. Bearing shells have drilled holes which line up with an oil groove in the rod bearing seat. Oil from this groove is forced to the piston pin through the drilled passage in the rod.

Fork and Blade (Plain) Connecting Rods

While two conventional rods are used to serve two cylinders in some V-type engines, a single assembly consisting of two rods is used in other engines of this type. As the name implies, one rod is fork-shaped at the crankshaft end to receive the blade rod. In general, fork and blade rods are similar to conventional rods in material and construction. However, design at the crankpin end (fig. 4-29) obviously differs from that of the conventional rods.

The bearings of fork and blade rods are similar to those already discussed, except that the shells must have a bearing surface on the outer surface to accommodate the blade rod. In some models, the metal used for bearing surfaces differs from that used in the bearings of many conventional rods. For example, in some high-speed, gasoline engines the shells are steel backed, and the inner surface is lined with lead-tin plated pure silver. A center band of silver (unplated) is applied to the outer surface of the shells to provide a bearing surface for the

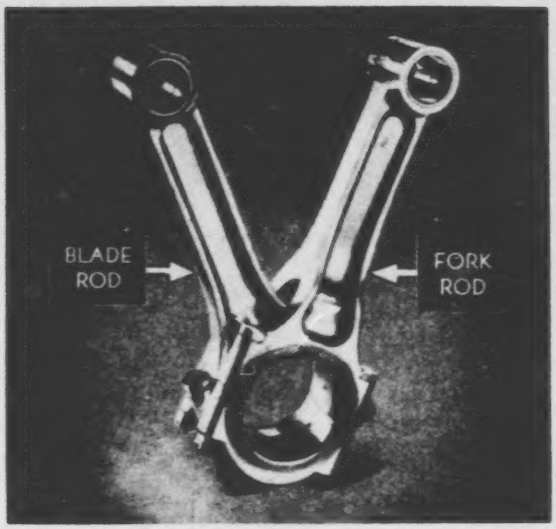

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Figure 4-29.–Fork and blade connecting rod.

blade rod. A variety of bearing materials is found in the crankpin bearings of some V-type diesel engines. In one model the upper shell is steel, lined inside and outside with lead-bronze bearing metal which is lead-tin plated. The lower shell is a solid chilled cast lead bronze, lead-tin plated, bearing.

CRANKSHAFTS

As one of the largest and most important moving parts in an engine, the crankshaft changes the movement of the piston and the connecting rod into the rotating motion that is needed to drive such items as reduction gears, propeller shafts, generators, pumps, etc.

As the name implies, the crankshaft consists of a series of cranks (throws) formed as offsets in a shaft. The crankshaft is subjected to all the forces developed in an engine. Because of this, the shaft must be of especially strong construction; it is usually machined from forged alloy or high-carbon steel. The shafts of some engines are made of cast iron alloy. Forged crankshafts are nitrided–heat treated–to increase the strength of the shafts and to minimize wear.

While crankshafts of a few larger engines are of the built-up type (forged in separate sections and flanged together), the crankshafts of most modern engines are of one-piece construction (fig. 4-30).

CRANKSHAFT TERMINOLOGY

The parts of a crankshaft may be identified by various words; however, the terms used in figure 4-30 are most commonly used in the manufacturer's technical manuals for the engines used by the Navy.

The MAIN JOURNALS serve as the points of support and as the center of rotation for the shaft. As bearing surfaces, the main journals and the connecting rod journals of most crankshafts are surface hardened so that a longer wearing, more durable bearing metal can be used without causing excessive wear of the shaft.

As illustrated in figure 4-20, crankshafts have a main journal (1 and 5) at each end of the shaft. Usually, there is an intermediate main journal (3) between the cranks; however, in small shafts, intermediate journals may not be used.

Each CRANK (throw) of a shaft consists of three parts, two webs and a pin. Crank webs are sometimes called cheeks or arms. The cranks, or throws, provide points of attachment for the connecting rods which are offset from the main journals.

In many crankshafts, especially in large engines, the connecting rod journals and main journals are of hollow construction. Hollow construction not only reduces weight considerably but also provides a passage for the flow of lubricating oil (fig. 4-31).

The forces that turn the crankshaft of a diesel engine are produced and transmitted to the crankshaft in a pulsating manner. These pulsations create torsional vibrations, which are capable of severely damaging an engine if they are not reduced, or damped, by opposing forces.

Many engines require an extra damping effect to ensure satisfactory operation. It is usually provided by torsional vibration dampers mounted on the free end of the crankshaft.

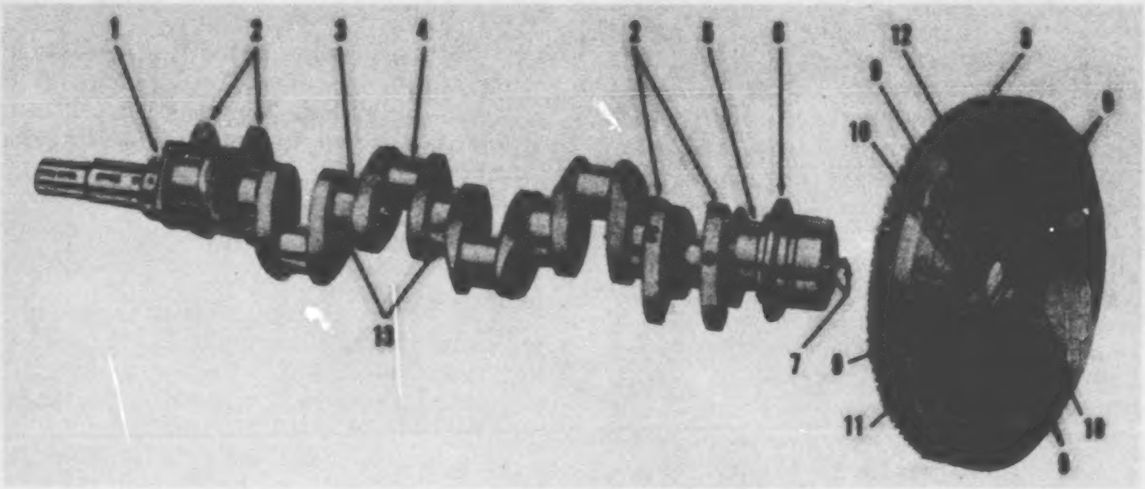

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Figure 4-30.—One-piece six-throw crankshaft with flywheel.

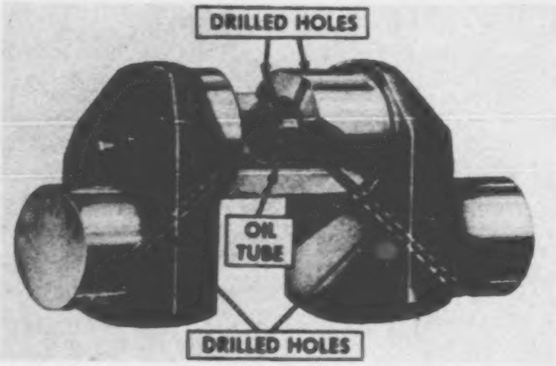

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Figure 4-31.—An example of hollow connecting rod journal construction.

Several types of torsional dampers are currently in use.

On some crankshafts, part of the web of the crankshaft extends beyond the main journal to form or to support counterweights. These counterweights may be integral parts of the web (fig. 4-30) or may be separate units attached to the web by studs and nuts. Counterweights balance the offcenter weight of the individual crank and thereby compensate for centrifugal force generated by each rotating crank. Without such balance, the crank action will create severe vibrations, particularly at the higher speeds. If such vibrations are not controlled, the shaft is likely to become damaged because excessive vibration causes rapid wear and leads to failure of metal structure. Counterweights use inertia to reduce the pulsating effect of power impulses in the same manner as the flywheel. Flywheels are described later in this chapter.

CRANKSHAFTS AND LUBRICATION

Whether a crankshaft is of solid construction (fig. 4-30) or of hollow construction (fig. 4-31), the main journals, the connecting rod journals, and the webs of most shafts have drilled passages for lubricating oil. Two other variations in the interior arrangement of oil passages in crankshafts are shown in figure 4-32. A study of these two oil passage arrangements will give you an idea of the part the crankshaft plays in engine lubrication.

In the system illustrated in part A of figure 4-32, each oil passage is drilled through from a main bearing journal to a connecting rod

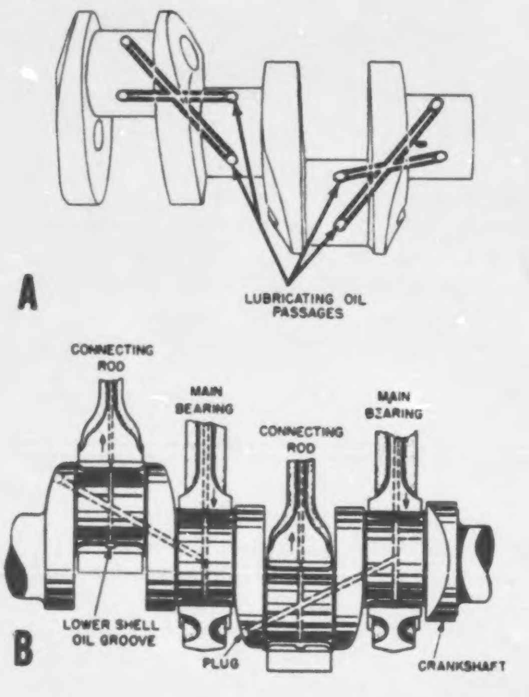

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Figure 4-32.—Examples of crankshaft oil passage arrangement.

journal. The oil passages are in pairs which crisscross each other in such a way that the two oil holes for each journal are on opposite sides of the journal. These holes are in axial alignment with the oil grooves of the bearing shells when the shells are in place. Since the oil groove in a bearing goes at least halfway around the bearing, a part of the groove will always be aligned with at least one of the holes.

In the oil passage arrangement shown in part B of figure 4-32 (shaft is shown in 4-30), the passage is drilled straight through the diameter of each main and connecting rod journal. A single diagonal passage is drilled from the outside of a crankshaft web to the center of the next main journal. The diagonal passage connects the oil passages in the two adjoining connecting rod journals and main journals. The outer end of the diagonal passage is plugged.

Lubricating oil under pressure enters the main bearing and is forced through the diagonal passage to lubricate the connecting rod bearing. From there it flows through the drilled connecting rod to lubricate the piston pin and cool the piston.

In engines that use crankshaft oil passage arrangements like those just discussed and like that shown in figure 4-31, the connecting rods are drilled to carry the lubricating oil to the piston pins and piston. Not all engine lubricating systems have drilled connecting rods. In some V-type engines that have a fork-and-blade type connecting rod, drilled passages supply oil to the main and connecting rod bearings, but oil from the lubrication and cooling of the piston assembly may be supplied by centrifugal force or by separate supply lines. Variations in engine lubricating systems are discussed later in another chapter.

CRANKSHAFT THROW ARRANGEMENTS

The smooth operation of an engine and its steady production of power depends, to a great extent, on the arrangement of the cranks on the shaft and on the firing order of the cylinders. To obtain uniform rotation of the crankshaft in a multicylinder engine, the power impulses must be equally spaced with respect to the angle of crankshaft rotation and, when possible, they must be placed so that successive explosions do not occur in adjacent cylinders. (This arrangement is not always possible, especially in 2-, 3-, and 4-cylinder engines.)

Crankshafts may be classified according to the number of throws–one throw, two throw, etc. The 6-throw shaft illustrated in figure 4-30 is for a 6-cylinder, in-line, 2-stroke cycle engine. Shafts of similar design can be used in a 12-cylinder, V-type engine and in a 24-cylinder pancake or vertical shaft engine.

The number of cranks and their arrangement on the shaft depend on a number of factors, such as the arrangement of the cylinders (in-line, V-type, pancake, flat, etc), the number of cylinders, and the operating cycle of the engine.

The arrangement of throws with respect to one another and with respect to the circumference of the main journals is generally expressed in degrees. In an in-line engine, the number of degrees between throws indicates the number of degrees the crankshaft must rotate to bring the pistons to TDC in firing order. This is not true in engines where each throw serves more than one cylinder. See figure 4-33 (foldout at end of chapter) which lists the examples of nine arrangements of throws with respect to cylinder arrangement, the number of cylinders served by each throw, and the firing order of the cylinders. (The sketches in fig. 4-33 are not drawn to scale and do not indicate relative size. The sketches are for illustrative purposes only.)

In studying the examples in figure 4-33, remember that the crankshaft must make only one revolution (360°) in a 2-stroke cycle; whereas two revolutions are required in a 4-stroke cycle. In examples (a) and (b), the shafts have the same number of throws, but other factors are somewhat different. Since the 4-cylinder engine in example (a) operates on the 4-stroke cycle, throws 1 and 3, 3 and 4, 4 and 2, and 2 and 1 (see firing order) must be 180° apart in order for the firing to be spaced evenly in 720° of crankshaft rotation. In the 16-cylinder pancake engine in example (b), the situation is somewhat different. Firing must take place within fewer degrees of shaft rotation in order for all cylinders to fire within the cycle. Since 16 cylinders must fire in 360° shaft rotation in a 2-stroke cycle engine, there can be only 22 1/2° shaft rotation between firings. To accomplish this, the connecting rod journals are spaced at unequal angles to obtain uniform cylinder firing intervals in the 90° cylinder banks. Shafts with the throw arrangements of this type are the exception and not the rule. Note that in all the other examples, the throws are equally spaced, regardless of cylinder arrangement, cycle of operation, or number of cylinders.

In examples (c) and (d), the shaft design and the number of degrees between throws are the same. Yet the shaft in example (d) fires twice as many cylinders. This is possible because one throw, through a fork-and-blade rod serves two cylinders which are positioned in 60° banks. Thus, even though both engines operate on the 4-stroke cycle, the 12-cylinder engine requires only 60° shaft rotation between power impulses.

In examples (e) and (f), other variations in shaft throw arrangement and firing order are shown. Note that the differences are goverened to a great extent by the cylinder arrangement, the number of cylinders served by the shaft and by each throw, and the operating cycle of the engine. How these factors influence throw arrangement and firing order can be seen by comparing some of the examples. For instance, there are six throws shown in examples (c) and (e), yet they are 120° apart in one and 60° apart in the other. Why? The cylinder arrangement, the total number of cylinders, and the number of cylinders served by each throw are the same. In examples (c) and (e), the operating cycle is the controlling factor in throw arrangement. This is not true in examples (e) and (f). Both shafts have six throws located 60° apart, and the operating cycle is the same in both examples. However, the amount of crankshaft rotation between firings is 30° less in example (f) than in example (e). Then, the controlling factors in these examples are cylinder arrangement, total number of cylinders served, and the number of cylinders served by each throw. (In examples (f) and (i) in the Throw Arrangement (End View) column of figure 4-33, the numbers in parentheses identify the additional cylinders served by the throw; for instance, the numbers 1 (7) in example (f) signify that number 1 connecting rod journal serves cylinders 1 and 7.)

Examples (g) through (i) show variations in 8-throw crankshafts.

CAMSHAFTS

The camshaft is a shaft with eccentric projections, called cams, designed to control the operation of valves, usually through various intermediate parts as described in Chapter 5. Originally, cams were made as separate pieces and fastened to the camshaft. However, in most modern engines the cams are forged or cast as an integral part of the camshaft.

To reduce wear and to help them withstand the shock action to which they are subjected, camshafts are made of low-carbon alloy steel with the cam and journal surfaces carburized (case-hardened) before the final grinding is done.

The cams are arranged on the shaft to provide the proper firing order of the cylinders served. The shape of the cam determines the point of opening and closing, the speed of opening and closing, and the amount of the valve lift. If one cylinder is properly timed, the remaining cylinders are automatically in time. All cylinders will be affected if there is a change in timing.

The camshaft is driven by the crankshaft by various means, the most common being by gears or by a chain and sprocket. The camshaft for a 4-stroke cycle engine must turn at one-half the crankshaft speed; while in the 2-stroke cycle engine, it turns at the same speed as the crankshaft.

The location of the crankshaft differs in various engines. Camshaft locations depend on the arrangement of the valve mechanism. The location and operation of the camshaft in various types of engines is discussed and illustrated in the next chapter.

JOURNAL BEARINGS

In the past, journal bearings for internal-combustion engines were the poured babbitt type; that is, the babbit lining was poured (cast) directly in the bearing housing and cap. Poured bearings require hand scraping to obtain a finished fit to the journal; also, the bearing clearance must be adjusted by placing shims between the bearing housing and the cap. Poured babbitt type bearings are not commonly used in modern engines; instead, replaceable precision type bearings are used.

Precision type bearings, which act as supports and in which the main journal of the crankshaft revolves, are generally referred to as MAIN BEARINGS. Main bearings in most engines are of the sliding contact, or plain type, consisting of two half-shells. (See fig. 4-34.) The location of main engine bearings in one type of block is shown in figure 4-35.

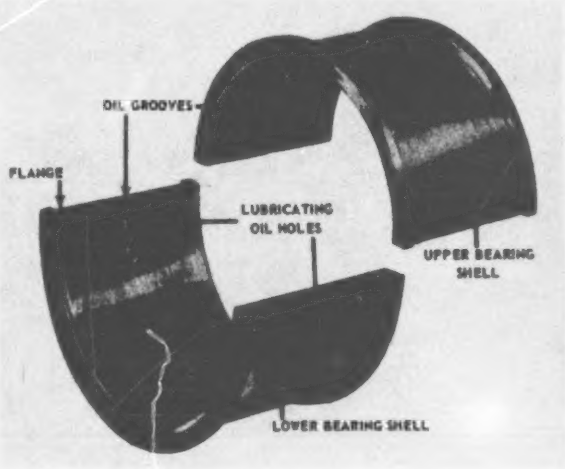

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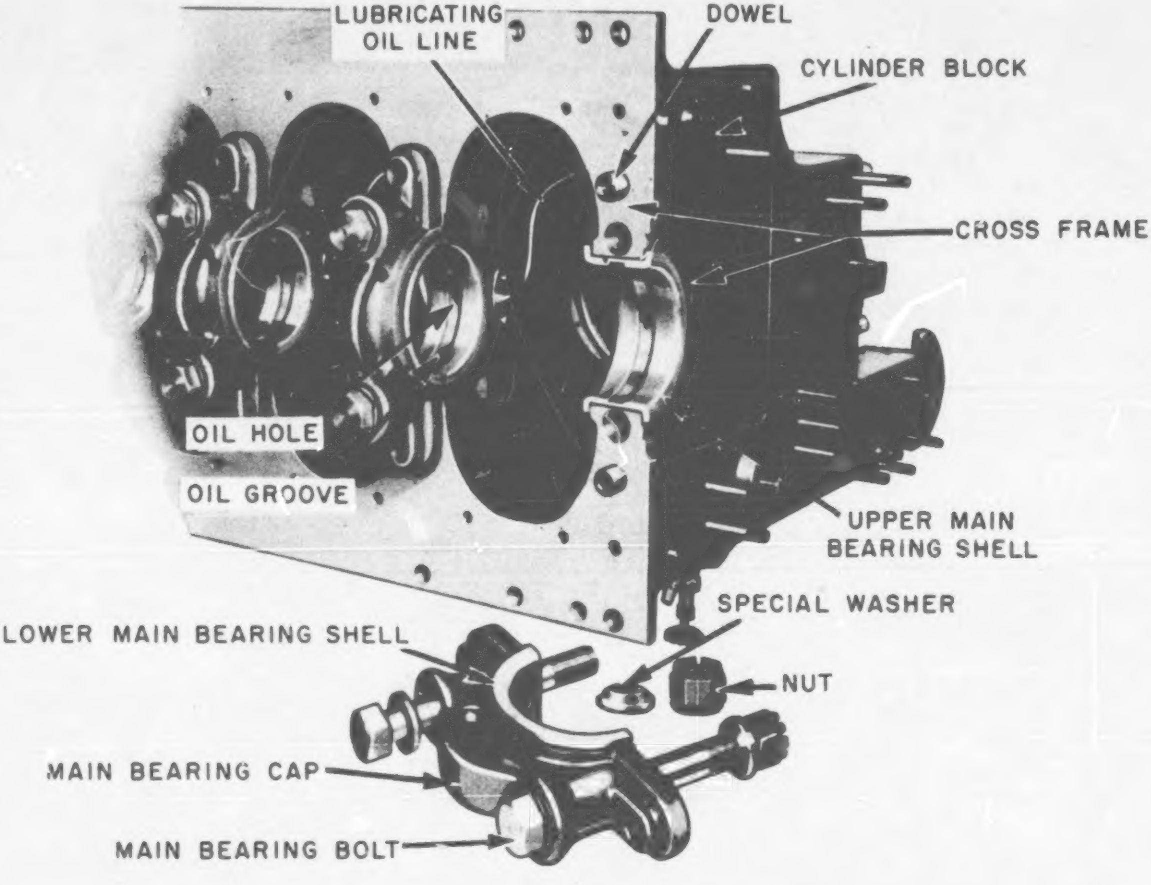
Figure 4-34.—Main journal bearing shells.

The main journal bearings of most marine engines used by the Navy may be divided into four principal groups according to the construction of the bearings and the materials used. One group includes the BRONZE-BACK SATCO and STEEL-BACK SATCO BEARINGS. These bearings are sometimes referred to as the bimetal type. This type of bearing consists of a bronze or steel back bonded with a bearing material of high lead content. The specifications for the back material are based on the type of bearing and the service for which it is intended. The bearing material, known as Satco, consists of about 98% lead and 1% tin.

Another group of bearings is the TRIMETAL bearings. A bearing of this type has a steel back bonded with an intermediate layer of bronze to which is bonded a layer of bearing material. The bearing material is either lead-base babbitt or tin-base babbitt.

COPPER-LEAD main journal bearings are usually constructed of a layer of copper-lead bonded to a steel back. Some of these bearings consist of only a copper-lead shell. Copper-lead bearings are sometimes plated with tin-lead or indium. The plating serves primarily as a


LUBRICATING OIL LINE
DOWEL
CYLINDER BLOCK
CROSS FRAME
OIL HOLE
OIL GROOVE
UPPER MAIN BEARING SHELL
SPECIAL WASHER
LOWER MAIN BEARING SHELL
NUT
MAIN BEARING CAP
MAIN BEARING BOLT

75.86X

Figure 4-35.—Main bearings in cylinder block.

protective coating against corrosion. Bearings of the copper-lead type are relatively hard; therefore, when copper-lead bearings are used, the journal surfaces of the shaft must be harder than those required when other types of bearings are used. This point should be kept in mind when bearings are being replaced.

Bearings made of ALUMINUM ALLOYS are becoming increasingly popular for use in diesel engines. These alloys may contain up to 6% tin. The bearings may be of either solid or bimetal construction.

Main bearings of the precision type with shims are installed in some large engines. Shims provide a means of adjustment to compensate for wear. The bearings of medium and small engines have no shim adjustment. When nonadjustable bearings have worn the prescribed amount, they must be replaced.

Main bearings and their housing and caps are precision machined with a tolerance sufficiently close that, when properly installed, the bearings are in alignment with the journals and fit with a predetermined clearance. The clearance provides space for the thin film of lubricating oil which is forced, under pressure, between the journals and the bearing surfaces. Under normal operating conditions, the film of oil surrounds the journals

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at all engine load pressures. Lubricating oil enters the bearing shells from the engine lubricating system, through oil grooves in the bearing shells. (See fig. 4-35.) These inlets and grooves are located in the low-pressure area of the bearing.

Main bearings are subjected to a fluctuating load, as are the connecting rod bearings and the piston pin bearings. However, the manner in which main journal bearings are loaded depends on the type of engine in which they are used.

In a 2-stroke cycle engine, a load is always placed on the lower half of the main bearings and the lower half of the piston pin bearings. In the connecting rod, the load is placed upon the upper half of the connecting rod bearings at the crankshaft end of the rod. This is true because the forces of combustion are greater than the inertia forces created by the moving parts.

In a 4-stroke cycle engine, the load is applied first on one bearing shell and then on the other. The reversal of pressure is the result of the large forces of inertia imposed during the intake and exhaust strokes. In other words, inertia tends to lift the crankshaft in its bearings during the intake and exhaust strokes.

BEARING TROUBLES

Bearings become a continual source of trouble unless personnel entrusted with operation of the engine follow the recommended operation and maintenance procedures exactly.

Severe bearing failures may be evidenced during engine operation by a pounding noise or by the presence of smoke in the vicinity of the crankcase. Impending failures may sometimes be detected by a rise in the lubricating oil temperature or a lowering of the lubricating oil pressure. Evidence of impending bearing failures may be detected during periodic maintenance checks or during engine overhauls by inspection of the bearing shells and backs for pits, grooves, scratches, or evidence of corrosion.

The indication of an impending failure does not necessarily mean that the bearing has completed its useful life. Journal bearings may perform satisfactorily with as much as 10% of the load-carrying area removed by fatigue failure. Other minor casualties may be repaired so that a bearing will give additional hours of satisfactory service.

Bearings should not be rejected or discarded for minor pits or minute scratches, however, areas indicating metallic contact between the bearing surface and the journal mean replacement is needed. Use a bearing scraping tool to smooth minute pits and raised surfaces. After performing work on bearings, make every effort to ensure that the bearing surfaces are clean. This also applies to the bearing back and the connecting rod journal. Place a film of clean lubricating oil on the journals and the bearing surfaces before they are reinstalled.

INSTALLATION OF JOURNAL BEARINGS

Always check the markings of the lower and upper bearing halves so that you install them correctly. Many bearings are interchangeable when new, but once they have become worn to fit a particular journal they must be reinstalled on that particular journal. You must mark or stamp each bearing half with its location (cylinder number) and the bearing position (upper or lower) to prevent incorrect installation.

You must pull the connecting rod bearing cap nuts down evenly on the connecting rod bolts to prevent possible distortion of the lower bearing cap and consequent damage to the bearing shells, cap, and bolts. Use a torque wrench (fig. 4-36) to measure the torque applied to each bolt and nut assembly. Apply the same torque to each bolt. If a manufacturer recommends the use of a torque wrench, the specified torque will be listed in the manufacturer's technical manual.

Another method for pulling down the nuts evenly is to stretch each bolt an equal amount and measure the distance from end to end of the bolt before and after tightening. Figure 4-37 shows the type of gage used, and figure 4-38 illustrates the gage in use. The proper elongation may be obtained from the engine manufacturer's technical manual.

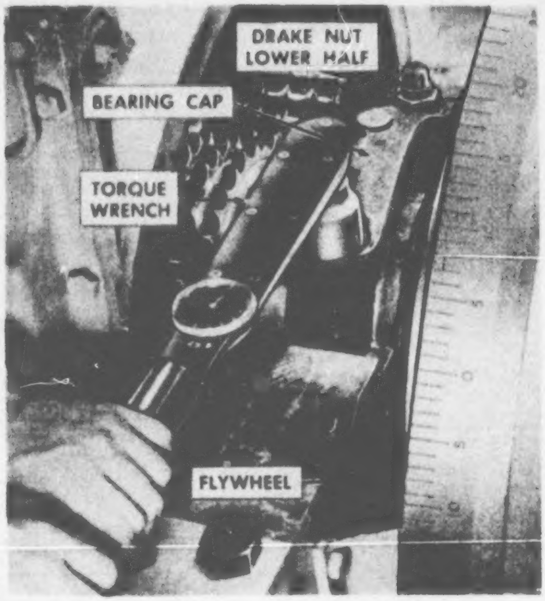

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Figure 4-36.—Using a torque wrench to tighten a main bearing.

After reassembling a bearing, always bar or jack over the engine by hand through several revolutions to ensure that all reciprocating and rotating parts are functioning freely and that there is no binding between the main and connecting rod bearings and the crankshaft. The larger diesel engines must be turned over, first by the manual jacking gear provided and, then, by the engine starting system.

Measuring Bearing Clearances

The use of leads, shim stock, or other such devices is not recommended for determining the clearance of precision bearings. If they are used, the soft bearing material could be seriously damaged. You should use a micrometer especially fitted with a spherical seat to obtain the thickness of bearing shells. Place the spherical tip against the inside of the bearing shell to obtain an accurate reading and to prevent injury to the bearing material. Figure 4-39 shows a micrometer caliper especially fitted with a steel ball for measuring bearing thickness.

An alternate method of obtaining clearance is with a Plastigage (fig. 4-40). The Plastigage will not leave an impression in the soft bearing metal because the gage material is softer than the bearing. To use this method, place a length of the Plastigage of proper gage across the bearing. Then, assemble the bearing cap and tighten it in place; when using this method, DO NOT TURN the crankshaft, as that would destroy the Plastigage. Now, remove the bearing cap; the width of the Plastigage, after crushing, will give a reading of the exact clearance, by reference to the accompanying chart on the Plastigage package.

Measurements must be taken at specified intervals, usually at every overhaul, to establish

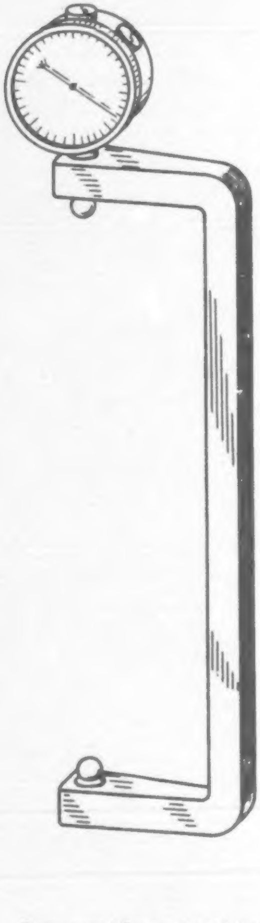

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Figure 4-37.—Gage used for measuring bolt elongation.

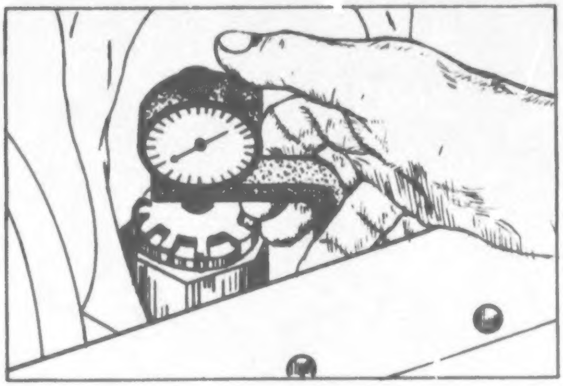

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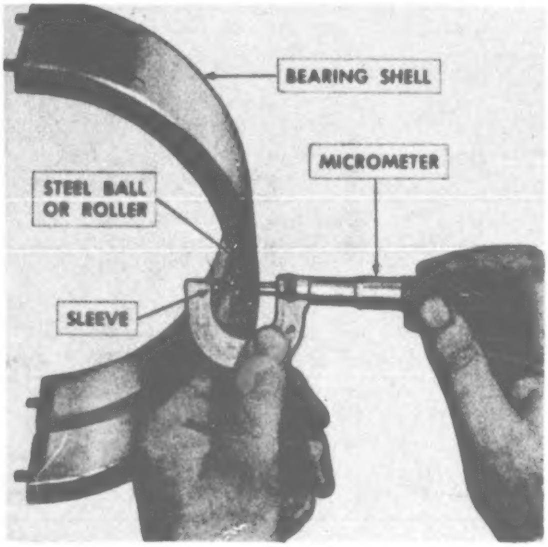
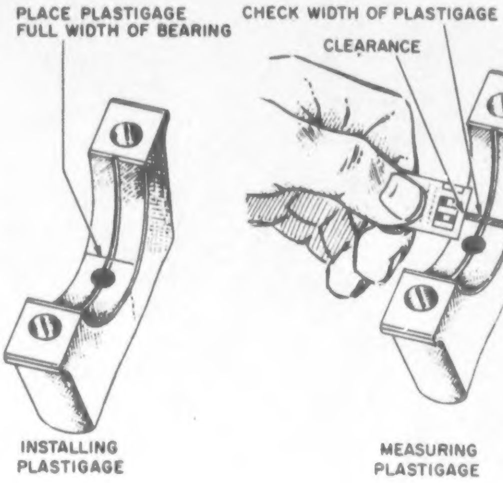
Figure 4-38.–Measuring bolt elongation.


BEARING SHELL
MICROMETER
STEEL BALL OR ROLLER
SLEEVE

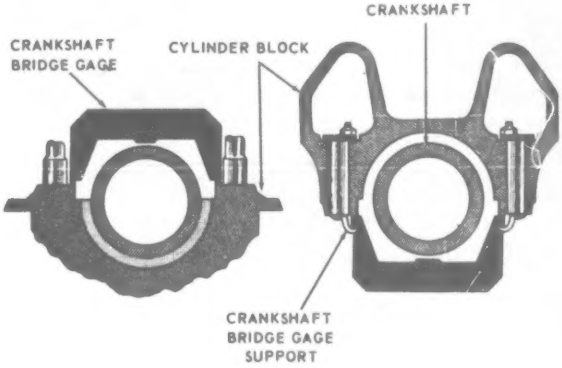
75.89

Figure 4-39.–Measuring bearing shell thickness.


PLACE PLASTIGAGE FULL WIDTH OF BEARING
CHECK WIDTH OF PLASTIGAGE
CLEARANCE
INSTALLING PLASTIGAGE
MEASURING PLASTIGAGE

75.327

Figure 4-40.–Checking bearing clearance with a Plastigage.


CRANKSHAFT
CRANKSHAFT BRIDGE GAGE
CYLINDER BLOCK
CRANKSHAFT BRIDGE GAGE SUPPORT

75.90

Figure 4-41.–Crankshaft bridge gage.

the amount of bearing wear. A sufficient number of crankshaft journal diameter measurements should be taken at suitable points, to determine possible out-of-roundness.

With some types of engines, a crankshaft bridge gage (fig. 4-41) is used to check the wear of the main bearing shells. Place the gage on the crankshaft, as shown, and measure the clearance between the bridge gage and shaft with a feeler gage. Any variation between the measured clearance and the correct clearance (usually stamped on the housing of each bearing) indicates that main bearing wear has occurred. The maximum limits of wear are listed in the manufacturer's technical manual. Some engine manufacturers recommend that bridge gage readings be taken at every overhaul in conjunction with crank web deflection measurements.

REPAIR OF SHAFTS AND JOURNAL BEARINGS

The repair of crankshafts, camshafts, and bearings varies depending on the extent of damage. There is no doubt about the necessity for replacing such items as broken or bent crankshafts and camshafts, camshafts with damaged integral cams, and failed camshaft bearings. Out-of-round journals may be reground and undersize bearing shells may be installed, but this requires personnel skilled in the use of precision tools. If available, a new shaft should be installed, and the damaged shaft should be sent to a salvage reclamation center. Under certain conditions, scored crankshaft journals or damaged journal bearings may be kept in service if proper repair is performed.

Repair of SCORED JOURNALS depends upon the extent of scoring. If a crankshaft has been overheated, the effect of the original heat treatment will have been destroyed, and it will be advisable to replace the crankshaft.

If journal scoring is only slight, you can use an oilstone for dressing purposes if you take precautionary measures with respect to abrasives during the procedure. During the dressing operation, you should plug all oil passages within the journal and those connecting the main bearing journal and the adjacent connecting rod journal.

In the dressing procedure, use a fine oilstone, followed with crocus cloth, to polish the surface. After dressing, always wash the journals with diesel oil. This procedure must include washing of the internal oil passages as well as the outside journal surfaces. Some passages are large enough to accommodate a cleaning brush; smaller passages can be cleaned by blowing them out with compressed air. The passages should always be dried by blowing compressed air through them.

NEVER STOW A CRANKSHAFT OR BEARING PART ON ANY METAL SURFACE. When you remove a shaft from an engine, you must place it on a wooden plank with all journal surfaces protected. If the shaft is to be exposed for some time, you should protect each journal surface with a coating of heavy grease. Always place bearings on wooden boards or clean cloths.

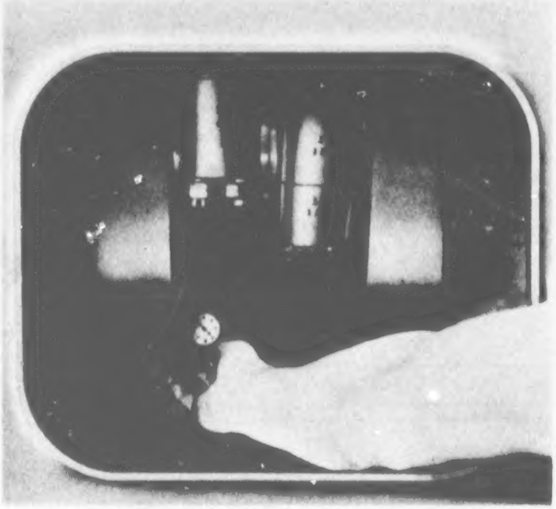


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Figure 4-42.—Strain gage between crank webs.

CRANKSHAFT overhaul consists of an inspection and servicing for scoring and wear and, also, a determination of each crank web deflection. Crank web deflection readings should be taken in accordance with the Planned Maintenance System.

A strain gage, often called a crank web deflection indicator, is used to take deflection readings. The gage is merely a dial-reading inside micrometer used to measure the variation in the distance between adjacent crank webs as the engine shaft is barred over. Figure 4-42 shows a strain gage between crank webs.

When installing the gage, or indicator, between the webs of a crank throw, be sure that the gage is placed as far as possible from the axis of the connecting rod journal. The ends of the indicator should rest in prick-punch marks in the crank webs. If these marks are not present, you must make them so that the indicator can be placed in its correct position. Consult the

95

manufacturer's technical manual for the proper location of new marks.

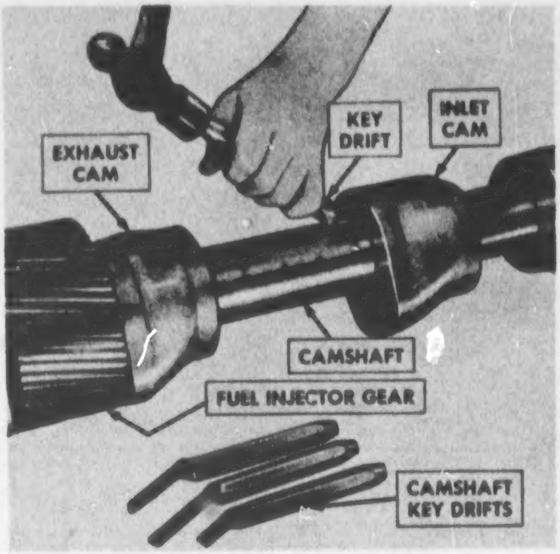
Readings are generally taken at the four crank positions: top dead center, inboard, near or at bottom dead center, and outboard. In some engines, it is possible to take readings at bottom dead center. In others the connecting rod may interfere, making it necessary to take the reading as near as possible to bottom dead center without having the gage come in contact with the connecting rod. When the gage is in its lowest position, the dial will be upside down, making it necessary to use a mirror and flashlight to obtain a reading. NOTE: Once the indicator has been placed in position for the first deflection reading, the gage should NOT be touched until all four readings have been taken and recorded.

Deflection readings are also used to determine correct alignment between the engine and the generator or between the engine and the coupling. However, when determining alignment, you should take a set of deflection readings at the crank nearest the generator or the coupling. In aligning an engine and generator, you may need to install new chocks between the generator and its base to bring the deflection within the allowable value. You may also need to shift the generator horizontally to obtain proper alignment. To align an engine and a coupling, first, correctly align the coupling with the drive shaft; then, properly align the engine to the coupling, rather than aligning the coupling to the engine.

CAMSHAFTS can be saved when the cams alone are damaged, if the cams are of the individual type, since such cams may be removed and replaced. Figure 4-43 illustrates the method of removing an individual cam from its shaft.

When a camshaft is removed from the engine, it must be thoroughly cleaned. You may use kerosene or diesel fuel. After cleaning the shaft, dry it with compressed air. After cleaning the cam and journal surfaces, inspect them for any signs of scoring, pitting, or other damage.

When inserting or removing a camshaft by way of the end of the camshaft recess, you should rotate the shaft slightly. Rotating the camshaft allows it to enter easily and reduces the possibility of damage to the cam lobes and the bearings.



75.92

Figure 4-43.—Removing an individual cam.

FLYWHEELS

The speed of rotation of the crankshaft increases each time the shaft receives a power impulse from one of the pistons; the speed then gradually decreases until another power impulse is received. If permitted to continue unchecked, these fluctuations in speed (their number depending upon the number of cylinders firing on one crankshaft revolution) would result in an undesirable situation with respect to the driven mechanism as well as to the engine; therefore, some means must be provided to stabilize shaft rotation. In some engines, this is accomplished by installing a flywheel on the crankshaft; in others, the motion of such engine parts as the connecting rod journals, webs, and lower ends of connecting rods, and such driven units as the clutch and generator, serve the purpose. The need for a flywheel decreases as the number of cylinders firing in one revolution of the crankshaft and the mass of the moving parts attached to the crankshaft increases.

A flywheel stores up energy during the power event and releases it during the remaining events of the operating cycle. In other words, when the speed of the shaft tends to increase, the flywheel absorbs energy; when the speed tends to decrease, the flywheel gives up energy to the shaft in an effort to keep shaft rotation uniform. In doing this, a flywheel (1) keeps variations in speed within desired limits at all loads; (2) limits the increase or decrease in speed during sudden changes of load; (3) aids in forcing the piston through the compression event when an engine is running at low or idling speed; and (4) provides leverage or mechanical advantage for a starting motor.

Flywheels are generally made of cast iron, cast steel, or rolled steel. Strength of the material from which the flywheel is made is of prime importance because of the stresses created in the metal of the flywheel when the engine is operating at maximum designed speed.

In some engines, a flywheel is the point of attachment for such items as a starting ring gear, turning ring gear, or an overspeed safety mechanism. The rim of a flywheel may be marked in degrees. With a stationary pointer attached to the engine, the degree markings can be used to determine the position of the crankshaft when the engine is being timed.

JACKING GEARS

Diesel main drive installations are equipped with a means of jacking, or turning over, an engine or reduction gears. A great majority of diesel engines are jacked over by hand, particularly the smaller, high-speed engines that drive generators.

For instance, the reversible engine (fig. 4-44) is provided with a turning gear at the forward end of the engine. The turning gear, manually operated by means of a removable handcrank, can be used to jack the engine in either direction. (When it is necessary to rotate the crankshaft only a few degrees, the operator should use a bar inserted in one of the holes provided in the rim of the flywheel.)

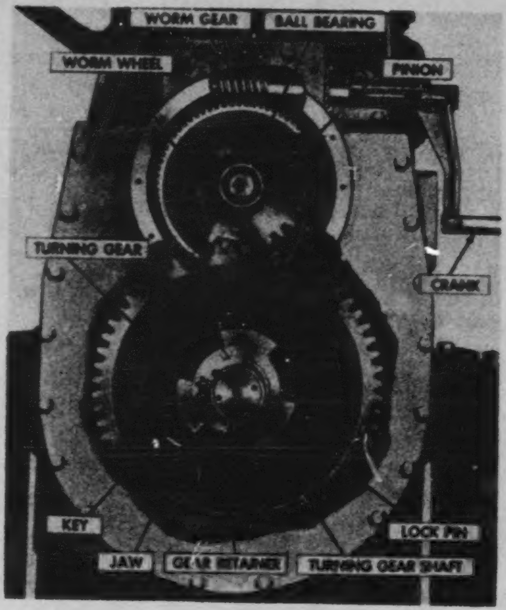


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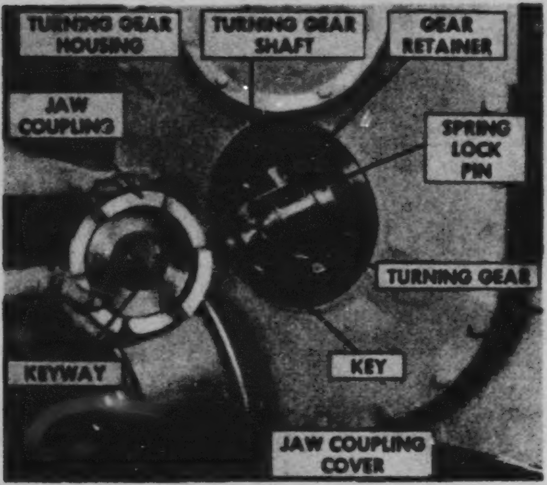
Figure 4-44.—Crankshaft turning gear assembly.

The turning gear of the engine is engaged by means of a three-jaw coupling which slides axially along the turning gear (fig. 4-45). The coupling is held in either the disengaged or the engaged position by a small spring-lock pin in the turning gear shaft. You may depress the spring-lock pin with a screwdriver or small rod. To put the jaw coupling in place on the turning gear shaft, you must remove the welded steel cap on the end of the shaft. (The entire gear train of the turning gear is enclosed in a welded steel housing, doweled and bolted to the engine base and cylinder block. The welded steel cap is in turn bolted to the housing, directly over the turning gear shaft.)

When the handcrank is in position, it engages a tapered shank on the worm gear shaft, shown in figure 4-46. (Note: Be sure to disengage the turning gear and remove the handcrank before attempting to start the engine.) The steel worm gear engages a bronze worm wheel, which is in turn keyed to the pinion shaft. The pinion gear, also keyed to the pinion shaft, engages the large


TURNING GEAR HOUSING
TURNING GEAR SHAFT
GEAR RETAINER
JAW COUPLING
SPRING LOCK PIN
TURNING GEAR
KEYWAY
KEY
JAW COUPLING COVER

75.94

Figure 4-45.–Installing the jaw coupling on the turning gear.

steel turning gear which floats on the turning gear shaft.

The pinion shaft rotates on ball bearings, supported by the turning gear housing and by the cover plate which is bolted to the housing. The turning gear shaft, bolted to the end of the engine crankshaft, carries both the turning gear and the three-jaw coupling. The turning gear is located axially on the turning gear shaft by means of a bronze retainer, bolted to the hub face of the gear, and rides in a groove on the shaft.

When the coupling moves axially along the shaft, driving power is obtained through a key which is held in the keyway of the shaft by two screws. (The coupling has a keyway which permits it to slide along the shaft.)

Lubricating oil is supplied to the bearings on the floating gear through holes drilled in the crankshaft and the turning gear shaft. A pipe plug with a 1/4-inch hole is threaded into the end of the crankshaft to restrict the flow of oil. The forward ball bearing of the pinion shaft and the two ball bearings on the worm gear shaft are lubricated with grease, supplied through grease fittings.

However, some engines, such as the Fairbanks-Morse opposed-piston engine, are equipped with a mechanical barring (jacking) device, as shown in figure 4-47. The mechanical barring device is located on the crankshaft flexible coupling, operating through a helical worm gear. The driving worm gear (E) is mounted on a swing bracket (P) which holds the worms out of mesh, except during operation. As an additional safety feature, the swing bracket is held in the out-of-mesh position by a locking bolt (K). The interlock cable roller (G1) is mounted on the bracket shaft (A2) and holds the interlock stop plunger (J) up so that the interlock cam (H) and the control shaft (C) can be moved by the starting lever.

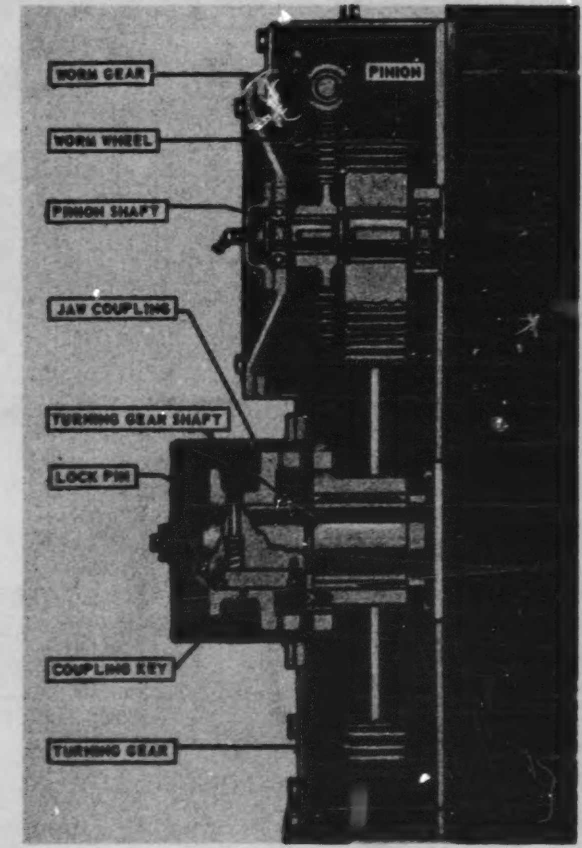

WORM GEAR
PINION
WORM WHEEL
PINION SHAFT
JAW COUPLING
TURNING GEAR SHAFT
LOCK PIN
COUPLING KEY
TURNING GEAR

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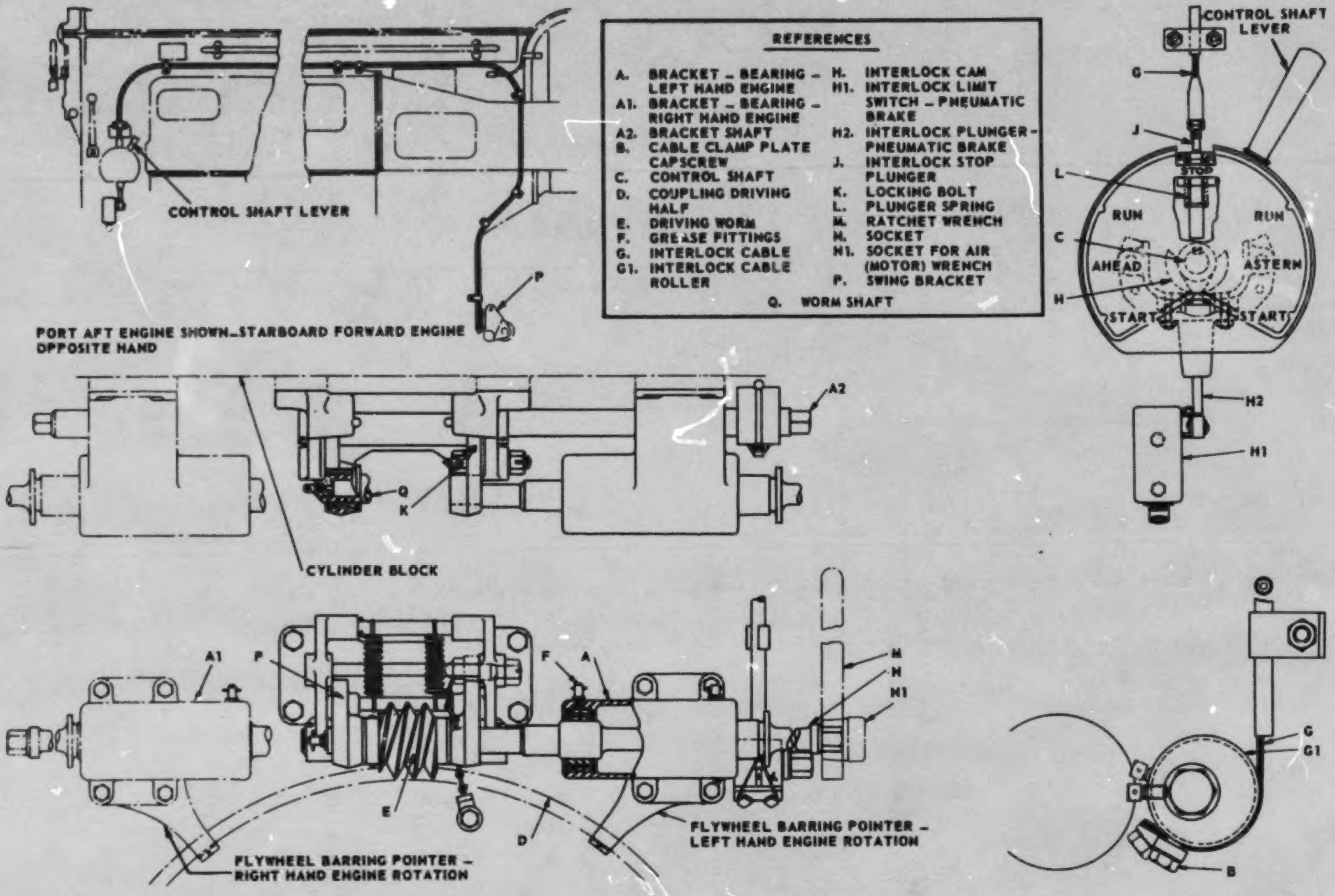
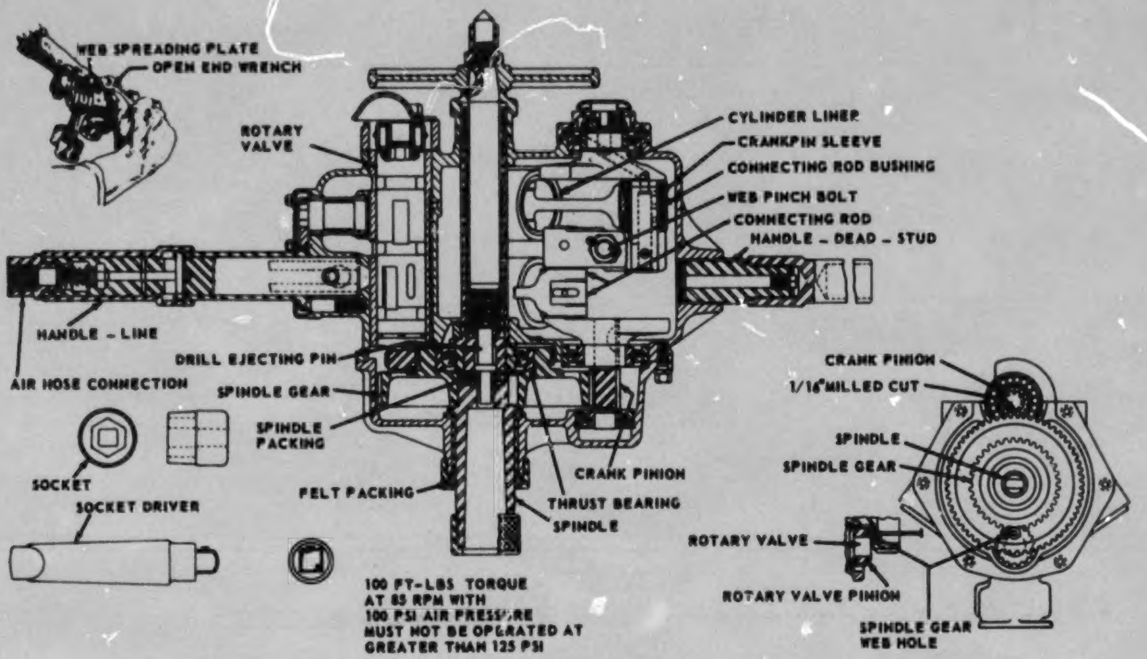
Figure 4-46.–Sectional view of crankshaft turning gear.


REFERENCES
A. BRACKET – BEARING – LEFT HAND ENGINE
A1. BRACKET – BEARING – RIGHT HAND ENGINE
A2. BRACKET SHAFT
B. CABLE CLAMP PLATE CAPSCREW
C. CONTROL SHAFT
D. COUPLING DRIVING HALF
E. DRIVING WORM
F. GREASE FITTINGS
G. INTERLOCK CABLE
G1. INTERLOCK CABLE ROLLER
H. INTERLOCK CAM
H1. INTERLOCK LIMIT SWITCH – PNEUMATIC BRAKE
H2. INTERLOCK PLUNGER – PNEUMATIC BRAKE
J. INTERLOCK STOP PLUNGER
K. LOCKING BOLT
L. PLUNGER SPRING
M. RATCHET WRENCH
N. SOCKET
N1. SOCKET FOR AIR (MOTOR) WRENCH
P. SWING BRACKET
Q. WORM SHAFT
CONTROL SHAFT LEVER
P
PORT AFT ENGINE SHOWN–STARBOARD FORWARD ENGINE OPPOSITE HAND
A2
Q
K
CYLINDER BLOCK
CONTROL SHAFT LEVER
G
J
L
C
H
STOP
RUN
RUN
AHEAD
ASTERN
START
START
H2
H1
A1
P
F
A
M
N
N1
E
D
FLYWHEEL BARRING POINTER – RIGHT HAND ENGINE ROTATION
FLYWHEEL BARRING POINTER – LEFT HAND ENGINE ROTATION
G
G1
B

75.96

Figure 4-47.--Barring device and interlock.


WEB SPREADING PLATE
OPEN END WRENCH
ROTARY VALVE
CYLINDER LINER
CRANKPIN SLEEVE
CONNECTING ROD BUSHING
WEB PINCH BOLT
CONNECTING ROD
HANDLE – DEAD – STUD
HANDLE – LINE
DRILL EJECTING PIN
AIR HOSE CONNECTION
SPINDLE GEAR
SPINDLE PACKING
SOCKET
SOCKET DRIVER
FELT PACKING
CRANK PINION
THRUST BEARING
SPINDLE
CRANK PINION
1/16"MILLED CUT
SPINDLE
SPINDLE GEAR
ROTARY VALVE
ROTARY VALVE PINION
SPINDLE GEAR WEB HOLE

100 FT-LBS TORQUE AT 85 RPM WITH 100 PSI AIR PRESSURE MUST NOT BE OPERATED AT GREATER THAN 125 PSI

75.97

Figure 4-48.–Air (motor) wrench and socket for barring the engine.

To operate the barring device (fig. 4-47), remove the locking bolt (K) and lower the swing bracket by turning the bracket shaft (A2) until the driving worm is meshed with the coupling driving half (D). Slide the socket (N) over the end of the worm shaft (Q) and rotate the engine by turning the socket with the ratchet wrench (M).

The barring device can also be operated by an air (motor) wrench, shown in figure 4-48, using the socket and the socket driver to turn the worm shaft of the device. When an airhose is attached to the hose connection and the line handle is turned, air is admitted to the rotary valve and cylinders, revolving the crankshaft through the connecting rods. The crank pinion meshes with the spindle.

The air (motor) wrench illustrated in figure 4-48 is the reversible, reciprocating type. A rotary-type air wrench also is used on some diesel engines.

Whenever the driving worm (E) is meshed with the coupling driving half (D), release the stop plunger (J) to provide a stop for the interlock cam (H) and control shaft (C) so that the worm gear (E) cannot be damaged by an attempted engine start. The interlock cam (H) also actuates the pneumatic brake on the propeller shaft, when the engine is to be reversed. The interlock plunger (H2) trips the limit switch (H1) to interrupt the electrical circuit to the solenoid coil at the propeller brake.

CHAPTER 5

ENGINE OPERATING MECHANISMS

To this point, we have considered only the main engine parts, both stationary and moving. At various points in the preceding chapters, we have made reference to the operation of some of the engine parts. However, we have said very little about the source of power which causes these parts to operate.

Frequently, the source of power that operates one engine part is also the source of power for other parts and accessories of the engine. For example, the source of power that operates engine valves may also be the source of power that operates such items as the governor; fuel, lubricating, and water pumps; and overspeed trips. Since mechanisms which transmit power to operate specific parts and accessories may be related to more than one engine system, we shall discuss these operating mechanisms before getting into the engine systems.

TYPES OF OPERATING MECHANISMS

The parts which make up the operating mechanisms of an engine may be divided into two groups: those which form the DRIVE MECHANISMS and those which form the ACTUATING MECHANISMS. The source of power for the operating mechanisms of an internal-combustion engine is the crankshaft.

As used in this chapter, "drive mechanism" identifies the group of parts which takes power from the crankshaft and transmits that power to various engine components and accessories. In engines, the drive mechanism does not change the type of motion, but it may change the direction of motion. For example, the impellers of a blower are driven or operated by a rotary motion from the crankshaft transmitted to the impellers by the drive mechanism, an arrangement of gears and shafts. While the type of motion (rotary) remains the same, the direction of motion of one impeller is opposite that of the other impeller as a result of the gear arrangement within the drive mechanism.

A drive mechanism may be gear, chain, or belt type. The gear type is the most common. Some engines use chain assemblies or a combination of gears and chains as the driving mechanism. Belts are not common on marine engines but are used as drive mechanisms on small engines.

Some engines have a single-drive mechanism which transmits power to operate engine parts and accessories. In some engines, there may be two or more separate mechanisms. When separate assemblies are used, the one which transmits power to operate the accessories is called the ACCESSORY DRIVE. Some engines have more than one accessory drive. A separate drive mechanism which is used to transmit power to operate engine valves is generally called the CAMSHAFT DRIVE or TIMING MECHANISM.

The camshaft drive, as the name implies, transmits power to the camshaft of the engine. The shaft, in turn, transmits the power through a combination of parts which causes the engine valves to operate. Since the valves of an engine must open and close at the proper moment (with respect to the position of the piston) and remain in the open and closed positions for definite periods of time, a fixed relationship must be maintained between the rotational speeds of the crankshaft and the camshaft. Camshaft drives are designed to maintain the proper relationship between the speeds of the

102

two shafts. In maintaining this relationship, the drive causes the camshaft to rotate at crankshaft speed in a 2-stroke cycle engine and at one-half crankshaft speed in a 4-stroke cycle engine.

"Actuating mechanism," as used in this chapter, is that combination of parts which receives power from the drive mechanism and transmits the power to the engine valves. In order for the valves (intake, exhaust, fuel injection, air start) to operate, there must be a change in the type of motion. In other words, the rotary motion of the crankshaft and drive mechanism must be changed to a reciprocating motion. The group of parts which, by changing the type of motion, causes the valves of an engine to operate is generally referred to as the VALVE ACTUATING GEAR or MECHANISM. A valve actuating mechanism may include the cams, cam followers, push rods, rocker arms, and valve springs. In some engines, the camshaft is so located that the push rods are not needed. In such engines, the cam follower is a part of the rocker arm. (Some actuating mechanisms are designed to transform reciprocating motion into rotary motion, but in internal-combustion engines most actuating mechanisms change rotary motion into reciprocating motion.)

There is considerable variation in the design and arrangement of the parts of operating mechanisms found in different engines. The size of an engine, the cycle of operation, the cylinder arrangement, and other factors govern the design and arrangement of the components as well as the design and arrangement of the mechanisms. Some of the variations in operating mechanisms are considered in the descriptions and illustrations which follow. The arrangements of operating mechanisms described in this chapter are representative of those commonly found in marine engines used by the Navy.

OPERATING MECHANISMS FOR A 2-STROKE CYCLE, IN-LINE DIESEL ENGINE

The operating mechanisms of some engines consist of a single-drive mechanism and the valve actuating mechanism. The 6-cylinder, GM 71 engine is an example of such an engine. A complete assembly which transmits power from the driving part to the driven part, the operating mechanism of the GM 71 consists of gears, shafts, couplings, and the parts of the valve-actuating mechanism.

GEARS

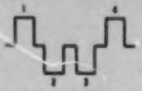
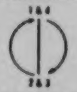
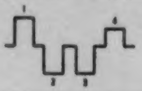
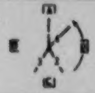
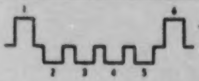
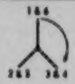
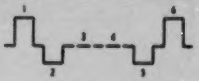
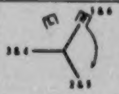
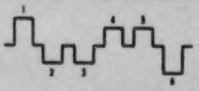
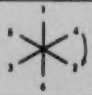
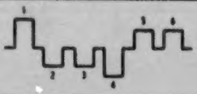
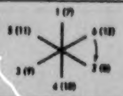
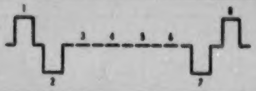
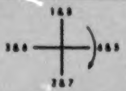
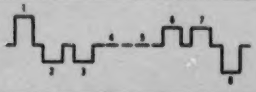
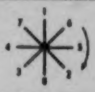
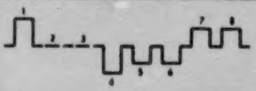
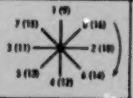
When the driving mechanism of an engine consists only of gears, the mechanism is commonly called a gear train. The gear train or drive for a GM 6-71 engine is shown in figure 5-1. (The arrangement shown is designed for right-hand rotation.)

The gear train of a GM 71 functions as both the camshaft drive and the accessory drive. The train consists of five helical gears completely enclosed at the rear end of the engine. Note that all gears are driven by the crankshaft gear through an idler gear. The idler gear may be located on either the right or left side of the engine (see "dummy hub," sometimes called "spacer," fig. 5-1), depending upon the direction of crankshaft rotation.

Since the engine operates on a 2-stroke cycle, the camshaft and balancer gears are driven at the same speed as the crankshaft gear. Either the camshaft gear or the balancer gear may be driven by the crankshaft gear through the idler gear; the drive arrangement depends on the model (right- or left-hand rotation). The camshaft and balance shaft gears are counterweighted for balance purposes.

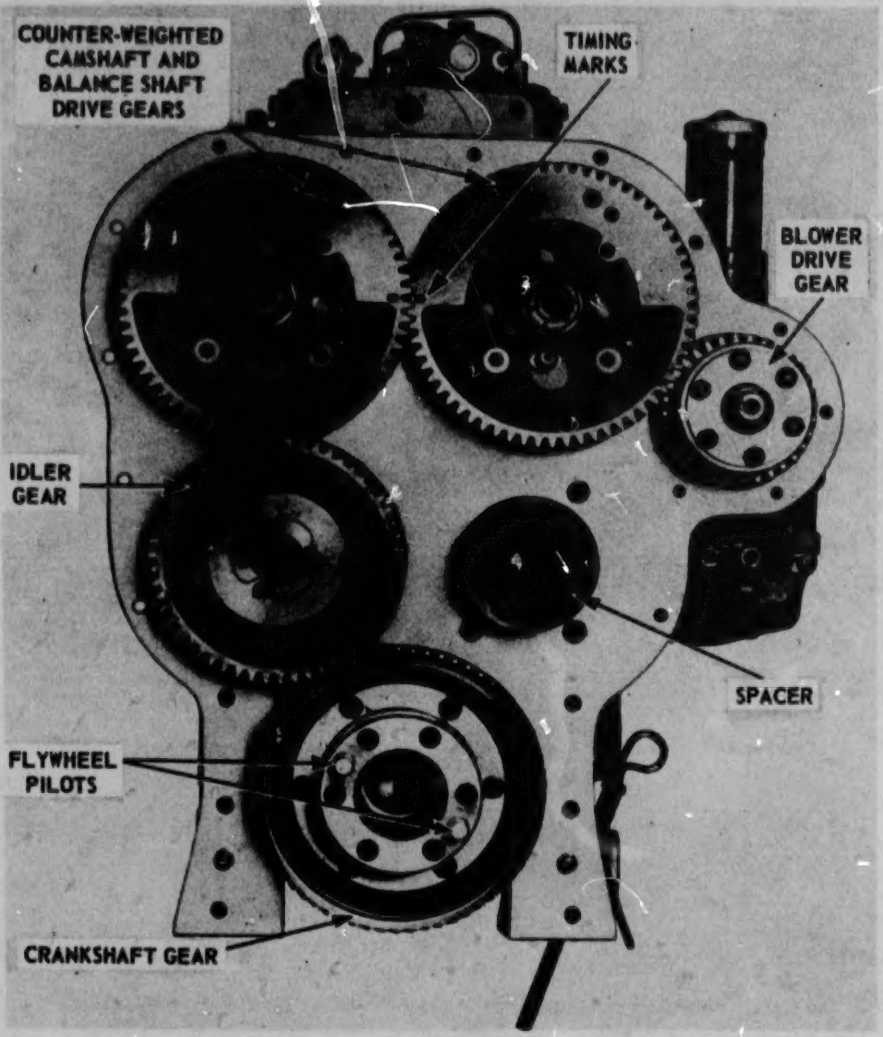
The accessories of the GM 71 receive power from the blower drive gear which is driven by the camshaft gear (fig. 5-1). Located on the blower side of the engine and supported by the rear end plate, the blower drive gear transmits power to the blower, governor, water pump, and fuel pump. (See fig. 5-2.)

Figure 5-2 shows the location of the various engine accessories and the shafts, gears, and couplings which transmit the power from the blower drive gear to each of the accessories.

EXAMPLE	NUMBER CYLINDERS	CYLINDER ARRANGEMENT	CYCLE	NO. CYL. SERVED BY EACH THROW	THROW ARRANGEMENT (SIDE VIEW)	THROW ARRANGEMENT (END VIEW)	FIRING ORDER	NO. DEGREES BETWEEN THROWS (SEE SKETCHES)	NO. DEGREES SHAFT ROTATION BETWEEN FIRINGS
(a)	4	IN-LINE	4-STROKE	1			1-3-4-2	4 THROWS 180° APART	180
(b)	16	PANCAKE	2-STROKE	4			BANK A, CYLINDER 1, C3, A4, B2, D1, B3, D4, A2, C1, A3, C4, D2, B1, D3, B4, C2	4 THROWS UNEVEN NO. DEGREES APART	22½
(c)	6	IN-LINE	4-STROKE	1			1-5-3-6-2-4	6 THROWS 120° APART	120
(d)	12	V	4-STROKE	2			L 1 2 3 4 5 6 R 1 2 3 4 5 6 [illegible]	6 THROWS 120° APART	60
(e)	6	IN-LINE	2-STROKE	1			1-5-3-6-2-4	6 THROWS 60° APART	60
(f)	12	V	2-STROKE	2		 1 (7) 5 (11) 6 (12) 3 (9) 2 (8) 4 (10)	1 2 3 4 5 6 7 8 9 10 11 12 1-11-5-9-3-10-6-8-2-12-4-7	6 THROWS 60° APART	30
(g)	8	IN-LINE	4-STROKE	1			1-3-2-5-8-6-7-4	8 THROWS 90° APART	90
(h)	8	IN-LINE	2-STROKE	1			1-7-4-3-8-2-5-6	8 THROWS 45° APART	45
(i)	16	V	2-STROKE	2		 1 (9) 7 (15) 8 (16) 3 (11) 2 (10) 5 (13) 6 (14) 4 (12)	9 10 11 12 13 14 15 16 1 2 3 4 5 6 7 8 1-15-7-11-3-13-5-12-4-14-6-10-2-16-8-9	8 THROWS 45° APART	22½

75.328

Figure 4-33.—Example of crankshaft throw arrangement.


COUNTER-WEIGHTED CAMSHAFT AND BALANCE SHAFT DRIVE GEARS
TIMING MARKS
BLOWER DRIVE GEAR
IDLER GEAR
SPACER
FLYWHEEL PILOTS
CRANKSHAFT GEAR

75.98X

Figure 5-1.—Camshaft and accessory drive (GM 6-71).

SHAFTS AND COUPLINGS

The shafts driven by the camshaft and balance shaft gears are shown in figure 5-3. While the shaft gears are not interchanged for a change in direction of engine crankshaft rotation, the shafts may be used on either side of the cylinder block, depending on the direction of crankshaft rotation.

The camshaft operates the mechanism which actuates the exhaust valves and the fuel injectors. The shaft is a one-piece drop-forging, case-hardened at the cams and journals. The cam lobes are heat-treated to provide a hard, wear-resistant surface. Each cylinder has a set of three cams. End and intermediate bearings are copper-lead, steel-backed bushings.

The balance shaft, which runs parallel to the camshaft on the opposite side of the block,

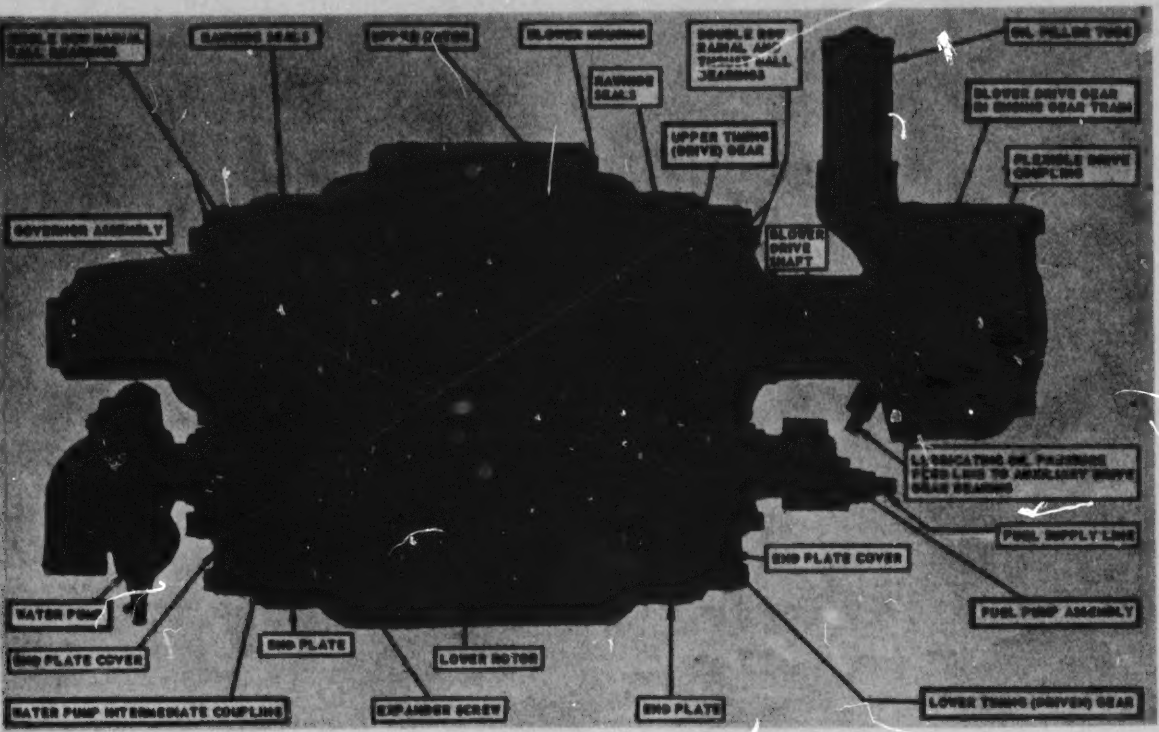
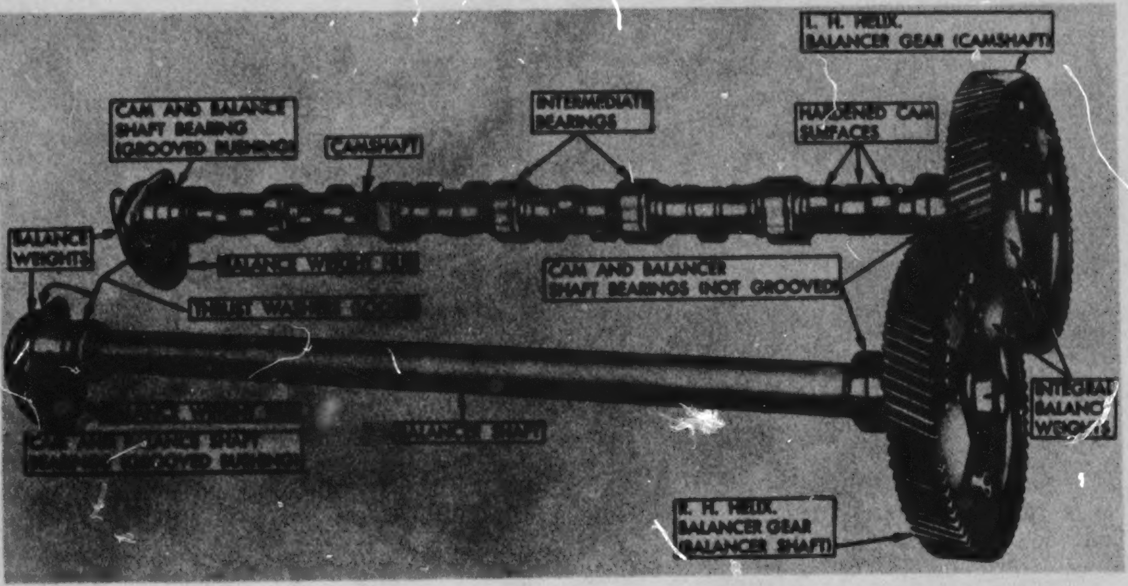
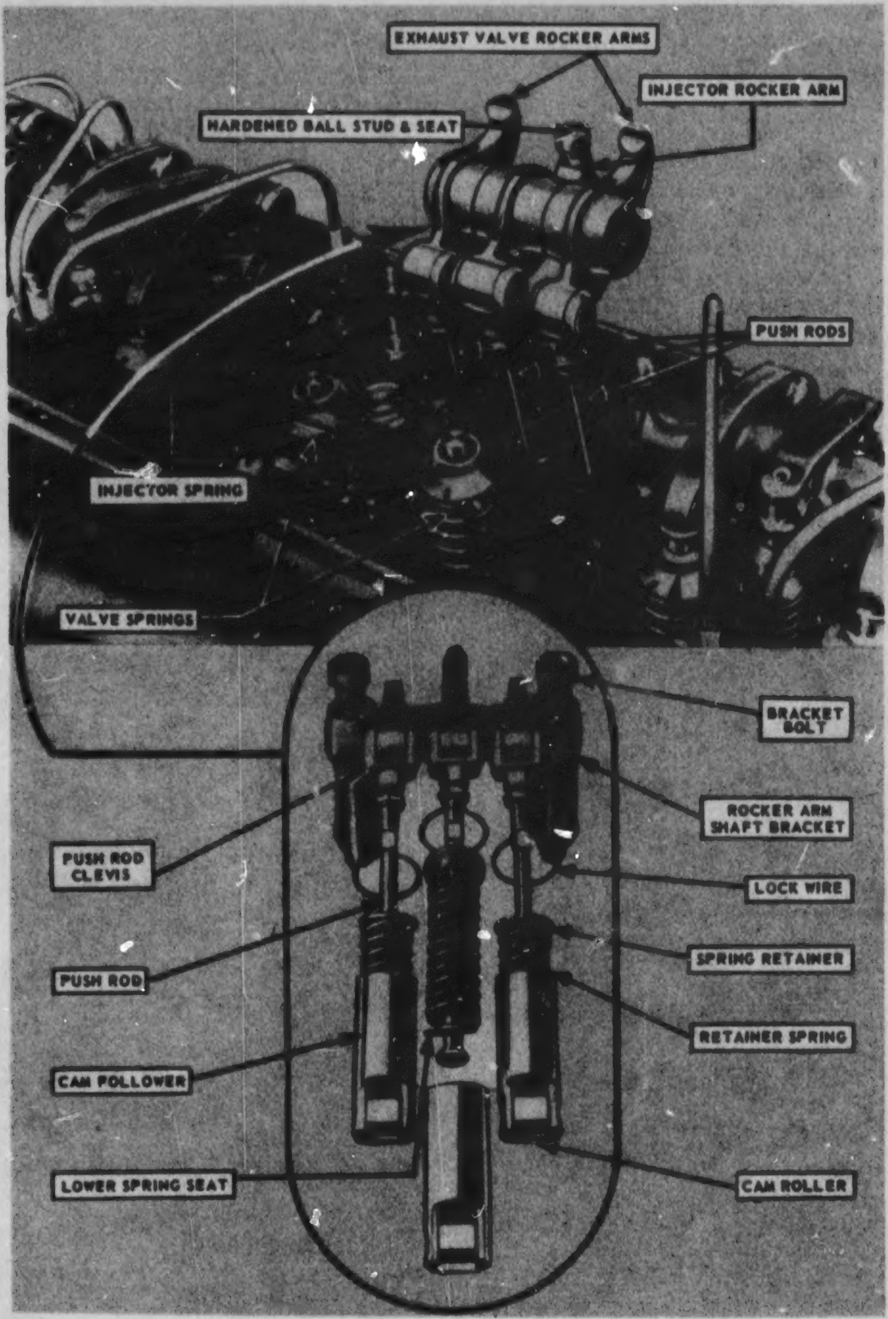

DOUBLE ROW RADIAL BALL BEARINGS
RAWHIDE SEALS
UPPER ROTOR
BLOWER HOUSING
RAWHIDE SEALS
DOUBLE ROW RADIAL AND THRUST BALL BEARINGS
OIL FILLER TUBE
BLOWER DRIVE GEAR IN ENGINE GEAR TRAIN
UPPER TIMING (DRIVE) GEAR
FLEXIBLE DRIVE COUPLING
GOVERNOR ASSEMBLY
BLOWER DRIVE SHAFT
LUBRICATING OIL PRESSURE FEED LINE TO AUXILIARY DRIVE GEAR BEARING
FUEL SUPPLY LINE
END PLATE COVER
FUEL PUMP ASSEMBLY
WATER PUMP
END PLATE
END PLATE COVER
LOWER ROTOR
WATER PUMP INTERMEDIATE COUPLING
EXPANDER SCREW
END PLATE
LOWER TIMING (DRIVEN) GEAR

Figure 5-2.—Blower assembly with accessories attached (GM 6-71). 75.99X


L. H. HELIX. BALANCER GEAR (CAMSHAFT)
CAM AND BALANCE SHAFT BEARING (GROOVED BUSHING)
CAMSHAFT
INTERMEDIATE BEARINGS
HARDENED CAM SURFACES
BALANCE WEIGHTS
BALANCE WEIGHT HUB
THRUST WASHER
CAM AND BALANCER SHAFT BEARINGS (NOT GROOVED)
INTEGRAL BALANCE WEIGHTS
BALANCE WEIGHT HUB
CAM AND BALANCE SHAFT BEARING (GROOVED BUSHING)
BALANCER SHAFT
R. H. HELIX. BALANCER GEAR (BALANCER SHAFT)

75.100X

Figure 5-3.—Cam and balancer shaft assemblies (GM 6-71).


EXHAUST VALVE ROCKER ARMS
INJECTOR ROCKER ARM
HARDENED BALL STUD & SEAT
PUSH RODS
INJECTOR SPRING
VALVE SPRINGS
BRACKET BOLT
ROCKER ARM SHAFT BRACKET
PUSH ROD CLEVIS
LOCK WIRE
SPRING RETAINER
PUSH ROD
RETAINER SPRING
CAM FOLLOWER
LOWER SPRING SEAT
CAM ROLLER

75.101X

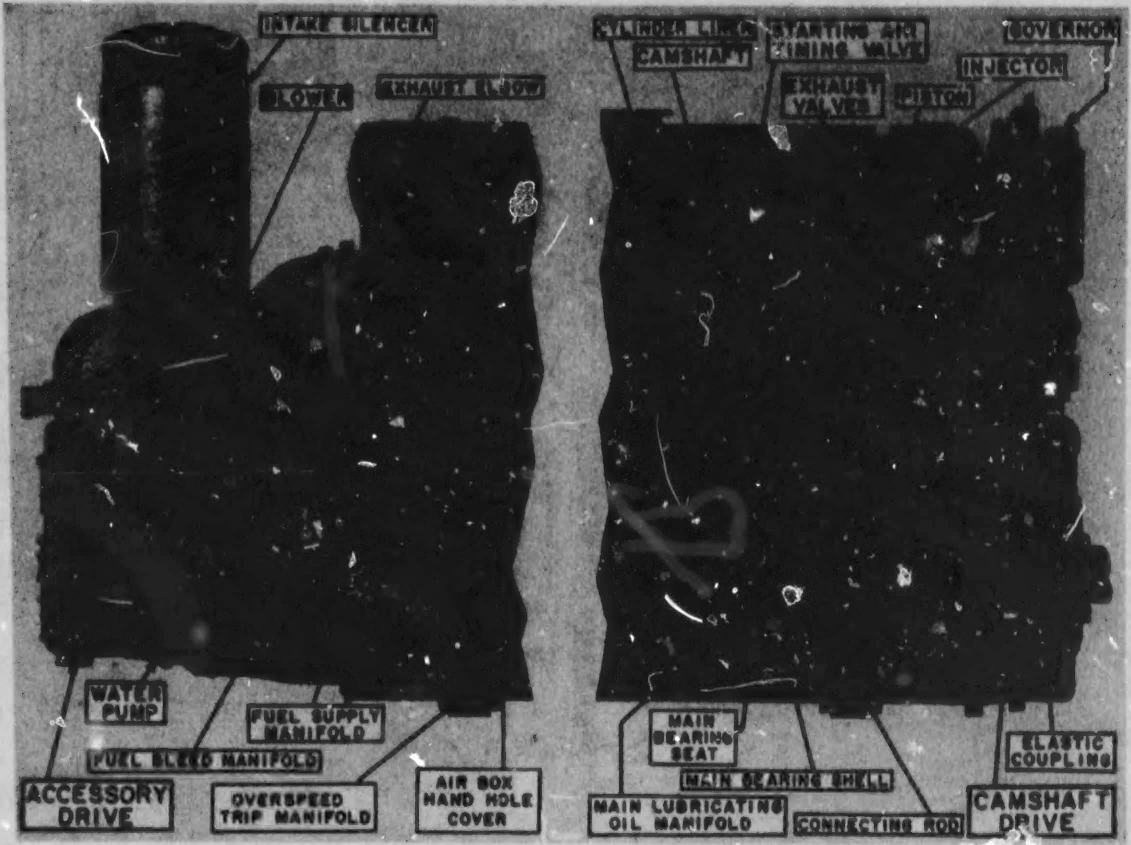
Figure 5-4.–Valve actuating mechanism (GM 6-71).

counterbalances the rotation of the weighted camshaft and causes a stabilizing action upon oscillatory impulses developed within the engine. (See fig. 5-3 for location of balance weights.)

The blower end of the governor drive shaft is serrated or splined and engages with corresponding serrations or splines inside the upper blower shaft. The fuel oil pump is bolted to the rear cover of the blower and is driven from the lower blower rotor shaft, through a device which acts as a universal joint. The water pump is mounted on the front end of the blower and is driven by the rotor shaft, through a coupling. (See fig. 5-2.)

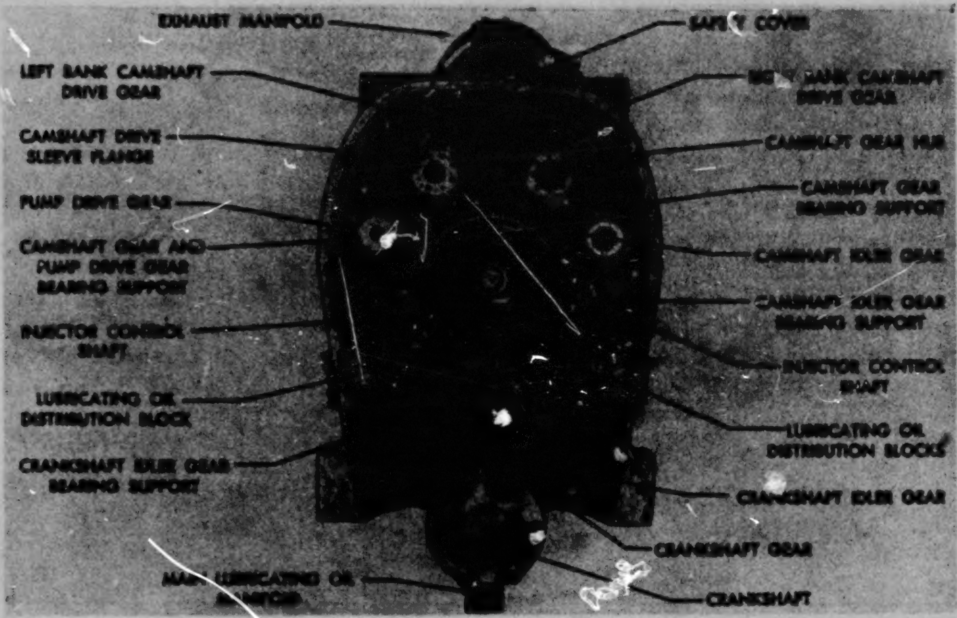
VALVE ACTUATING GEAR

The exhaust valves and the fuel injectors are actuated by a mechanism which is located in and attached to the cylinder head. A detailed view of the valve actuating mechanism is shown in figure 5-4. The insert shows the parts of the actuating mechanism for one cylinder. The mechanism includes three drop-forged rocker arms. The outer arms operate the exhaust valves and the inner arm operates the fuel injector. The rocker arms are actuated by the lobes of the camshaft through push rods. These parts, along with other parts essential to the assembly (fig. 5-1), change


INTAKE SILENCER
BLOWER
EXHAUST ELBOW
WATER PUMP
FUEL SUPPLY MANIFOLD
FUEL BLEED MANIFOLD
ACCESSORY DRIVE
OVERSPEED TRIP MANIFOLD
AIR BOX HAND HOLE COVER
CYLINDER LINER
CAMSHAFT
STARTING AIR TIMING VALVE
EXHAUST VALVES
PISTON
INJECTOR
GOVERNOR
MAIN BEARING SEAT
MAIN BEARING SHELL
MAIN LUBRICATING OIL MANIFOLD
CONNECTING ROD
ELASTIC COUPLING
CAMSHAFT DRIVE

75.102X

Figure 5-5.—Location of drive mechanisms in a V-type engine (GM 16-278A).


EXHAUST MANIFOLD
LEFT BANK CAMSHAFT DRIVE GEAR
CAMSHAFT DRIVE SLEEVE FLANGE
PUMP DRIVE GEAR
CAMSHAFT GEAR AND PUMP DRIVE GEAR BEARING SUPPORT
INJECTOR CONTROL SHAFT
LUBRICATING OIL DISTRIBUTION BLOCK
CRANKSHAFT IDLER GEAR BEARING SUPPORT
MAIN LUBRICATING OIL MANIFOLD
SAFETY COVER
RIGHT BANK CAMSHAFT DRIVE GEAR
CAMSHAFT GEAR HUB
CAMSHAFT GEAR BEARING SUPPORT
CAMSHAFT IDLER GEAR
CAMSHAFT IDLER GEAR BEARING SUPPORT
INJECTOR CONTROL SHAFT
LUBRICATING OIL DISTRIBUTION BLOCKS
CRANKSHAFT IDLER GEAR
CRANKSHAFT GEAR
CRANKSHAFT

75.103X

Figure 5-6.—Camshaft drive assembly, V-type engine (GM 16-278A).

the rotary motion of the camshaft into the reciprocating motion of the valves.

OPERATING MECHANISM OF A 2-STROKE CYCLE, V-TYPE DIESEL ENGINE

The in-line engine discussed in the preceding section is relatively small when compared to the GM 16-278A discussed in this section. Whereas the GM-71 requires only one drive mechanism to transmit power to the valve actuating gear and the engine accessories, the GM 16-278A uses two separate gear drives, one at each end of the engine. (See fig. 5-5.) The drive located at the coupling or power take-off end of the crankshaft is called the CAMSHAFT DRIVE. It transmits power to the valve operating mechanisms, the fuel injector operating mechanisms, and the starting-air timing valve; it drives the fuel pump, the lubricating oil pump, and the governor. The ACCESSORY DRIVE, located at the opposite end of the engine, drives the blower and the water pumps. Figure 5-5 shows the location of these drives and the engine parts and accessories to which they transmit power. Many of the engine parts that we have already discussed are also shown.

CAMSHAFT DRIVE AND VALVE ACTUATING GEAR

The camshaft gear train in the GM 16-278A is similar to that of the GM 6-71, except for two additional gears. Figure 5-6 shows an end view of the engine along with the camshaft drive assembly. Compare this assembly with that of the GM 6-71 in figure 5-1.

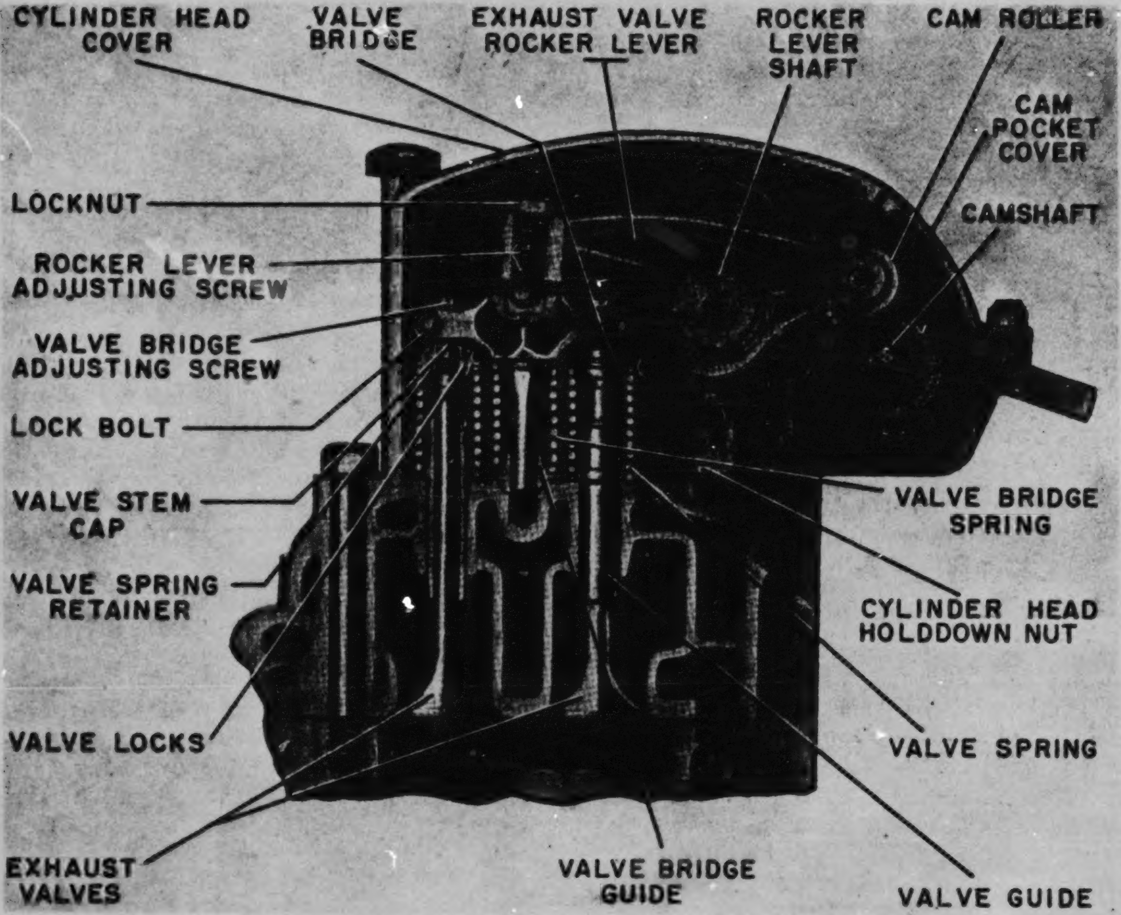
Gears and Couplings

Two camshaft gears are driven by the crankshaft gear at the power take-off or coupling end of the shaft, through the crankshaft and the camshaft idler gears. Both camshaft gears mesh with the camshaft idler gear. The lubricating oil pump gears are driven by the camshaft gears. A camshaft gear also furnishes power to drive the governor and the tachometer. In some models, the governor drive shaft is driven by the camshaft gear, through a flexible coupling. In other models, the shaft is flanged and bolted to a camshaft gear.

The train of gears in the camshaft drive is enclosed in an oiltight housing. A spring-loaded safety cover is fitted to a pressure relief opening in the top of the housing. (See fig. 5-6.)

Camshafts

Each cylinder bank of the engine is fitted with a camshaft. These shafts rotate at the same speed as the crankshaft, but in the opposite direction. Each shaft is made of two sections which are flanged and bolted together. The cams are case-hardened and are an integral part of each shaft section. As in the GM 6-71, each cylinder has three cams. In the GM 16-278A,


CYLINDER HEAD COVER
VALVE BRIDGE
EXHAUST VALVE ROCKER LEVER
ROCKER LEVER SHAFT
CAM ROLLER
CAM POCKET COVER
CAMSHAFT
LOCKNUT
ROCKER LEVER ADJUSTING SCREW
VALVE BRIDGE ADJUSTING SCREW
LOCK BOLT
VALVE STEM CAP
VALVE SPRING RETAINER
VALVE LOCKS
EXHAUST VALVES
VALVE BRIDGE GUIDE
VALVE BRIDGE SPRING
CYLINDER HEAD HOLDDOWN NUT
VALVE SPRING
VALVE GUIDE

75.24X

Figure 5-7.—Valve operating mechanism with valve bridge (GM 16-278A).

however, push rods are not needed for transmitting power.

Rocker Arms and Valve Bridges

Each cylinder head of the GM 16-278A is fitted with three rocker arms or levers. The two outer arms operate the exhaust valves and the inner arm operates the fuel injector. Since there are four exhaust valves per cylinder, each exhaust rocker arm (sometimes called a lever) must operate a pair of valves through a valve bridge. (See Fig. 5-7.)

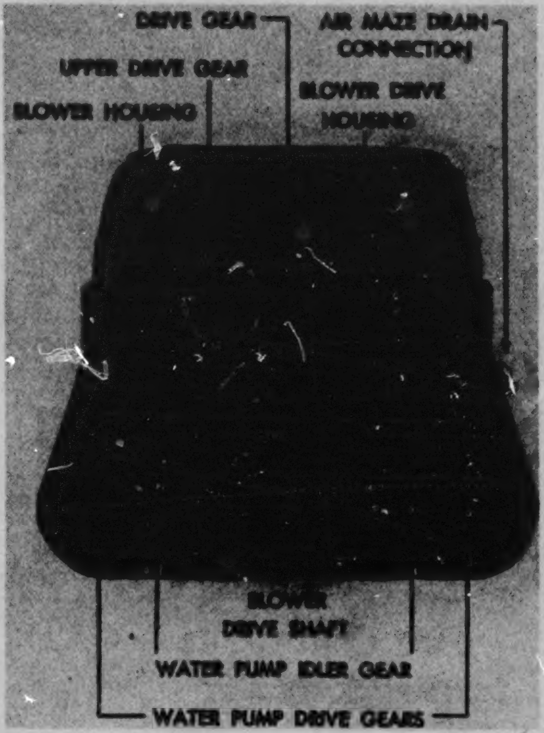
The valve bridge in this engine is made of forged steel and has a hardened ball socket into which the ball end of the rocker lever adjusting screw fits. The valve bridge has two arms, each of which fits over an exhaust valve.

The valve bridge spring keeps valve bridge tension off the valve stems until the bridge is actuated by the rocker arm. When the valve end of the rocker arm is forced down by the cam action, the valve bridge moves down, compressing the valve springs and opening the valves. By the time the action of the cam lobe has ceased, the valve springs will have closed the valves. The valve operating mechanism shown in figure 5-7 is representative of those in which the location of the camshaft eliminates the need for push rods. Note that the lobes of the cam come in direct contact with the rocker arm cam rollers.

ACCESSORY DRIVE

The gear train located on the front end of the engine (fig. 5-5) drives the blower and the water pumps. An end view of the assembly is shown in figure 5-8. The train consists of helical gears of forged steel which transmit the rotation of the crankshaft to the blower and the water pumps. The assembly is enclosed in a case which is bolted to the blower housing.

The drive gear is driven from the crankshaft through a splined shaft, one end of which fits into a hub that is bolted to the crankshaft while the other end fits into the blower drive gear hub. The drive gear operates the water pump gears through idler gears and meshes directly with the upper drive gear. The upper drive gear transmits power through a shaft to the rotor-driven gear of the blower gear assembly.

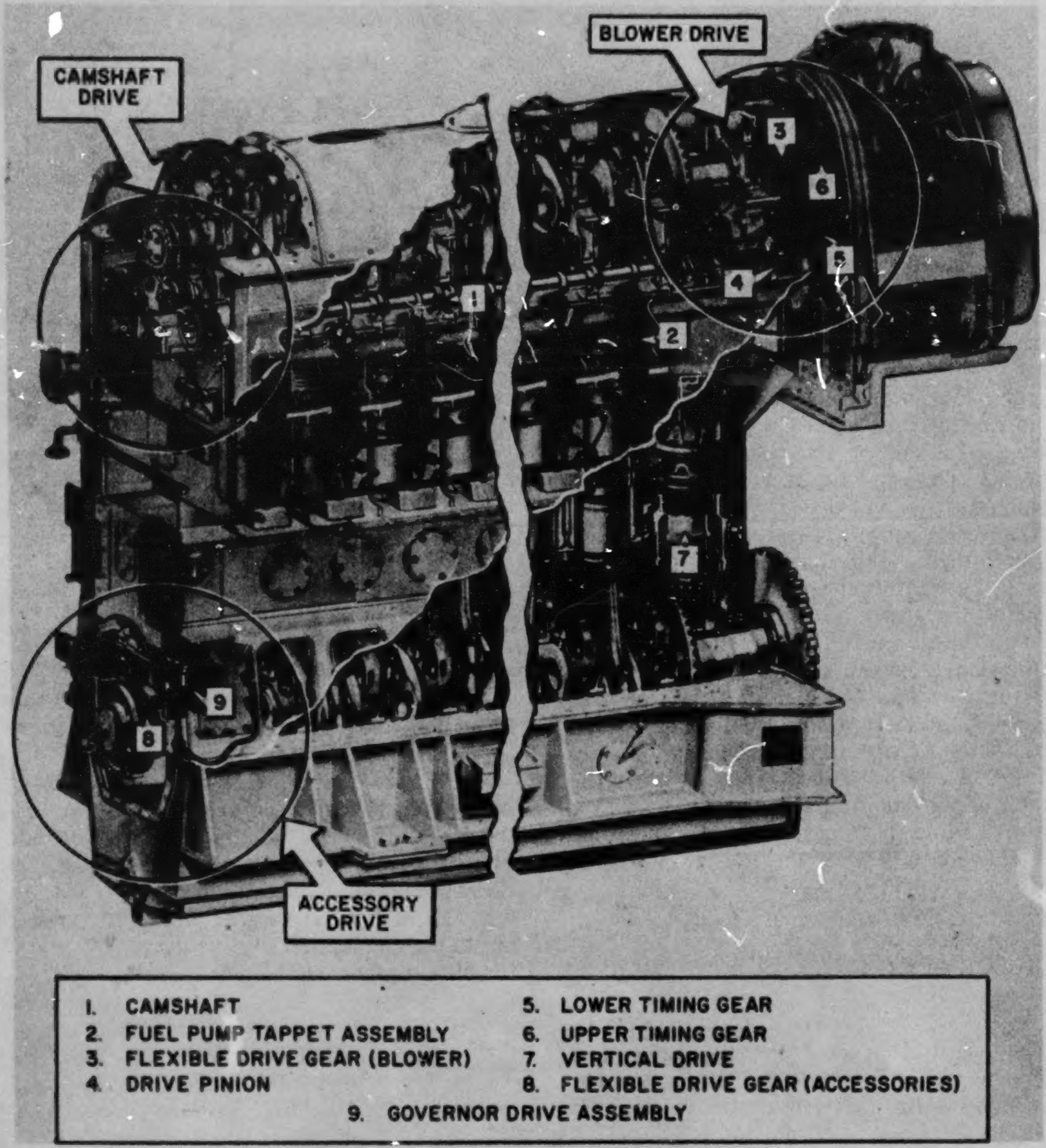


75.104X

Figure 5-8.—Accessory drive mechanism (GM 16-278A).

OPERATING MECHANISMS IN AN OPPOSED-PISTON DIESEL ENGINE

The operating mechanisms of opposed-piston engines will obviously differ, to a degree, from those of single-acting engines because of engine design differences. Some of the differences are because (1) power is supplied by two crankshafts in an opposed-piston engine, instead of one, and (2) ports are used instead of


CAMSHAFT DRIVE
BLOWER DRIVE
ACCESSORY DRIVE
1
2
3
4
5
6
7
8
9
I. CAMSHAFT
2. FUEL PUMP TAPPET ASSEMBLY
3. FLEXIBLE DRIVE GEAR (BLOWER)
4. DRIVE PINION
5. LOWER TIMING GEAR
6. UPPER TIMING GEAR
7. VERTICAL DRIVE
8. FLEXIBLE DRIVE GEAR (ACCESSORIES)
9. GOVERNOR DRIVE ASSEMBLY

75.105

Figure 5-9.—Location of drive mechanisms in an opposed-piston engine (FM 38D8 1/8).

valves for both intake and exhaust in an opposed-piston engine.

Regardless of differences in mechanisms, the basic types of drives–gear and chain–are found in both single-acting and opposed-piston engines. While the two engines described in preceding sections had only gear-type drive mechanisms, the opposed-piston engine used as an example in this section has chain assemblies as well as gear trains incorporated in the mechanisms which supply power to engine parts and accessories.

The Fairbanks-Morse opposed-piston engine used as an example in this section has three separate drive mechanisms. The drive which furnishes power to the camshaft and fuel injection equipment is the chain type. The blower and the accessories are operated by gear-type drives. The location of each drive is shown in figure 5-9.

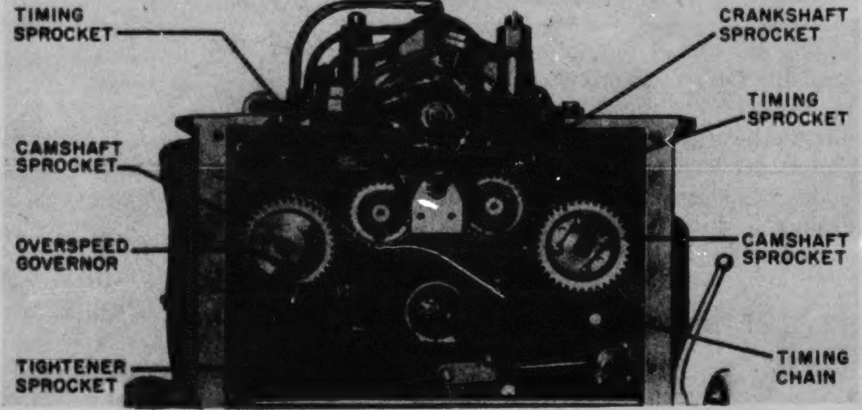
CAMSHAFT DRIVE AND FUEL PUMP ACTUATING GEAR

The camshaft drives of the engines we have discussed thus far supply power to one or more accessories as well as to the valve actuating gear. This is not true of the drive in an FM 38D opposed-piston engine. Since the FM 38D does not have cylinder valves and since two other drives are provided to operate the accessories, the primary purpose of the camshaft drive is to transmit power for, and to time the operation of, the fuel injection pumps.

Chain Assembly

The power required to operate the fuel injection pumps at the proper instant during the cycle of operation is transmitted through the camshafts from the crankshaft by a chain drive (frequently called the timing mechanism). The names and arrangement of the components of the drive are shown in figure 5-10. The drive sprocket is attached to the upper crankshaft at the control end of the engine. A sprocket is attached to the end of each camshaft and there are three other sprockets for timing and adjustment purposes.

The chain conveys the rotation of the upper crankshaft to the camshaft sprockets by passing over the crankshaft sprocket, under the two timing sprockets, over the two camshaft drive sprockets, and under the tightener sprockets. The timing sprockets are mounted on an



75.106X

Figure 5-10.–Camshaft drive and timing mechanism (FM 38D8 1/8).

adjustable bracket or lever. By moving the lever, the timing of the two camshafts can be adjusted. The adjustable tightener sprocket is used to obtain and maintain the proper slack in the chain.

Actuating Gear

The camshafts are located in the upper crankshaft compartment. (See No. 1, fig. 5-9.) Since engines of the opposed-piston type use ports for both intake and exhaust, the camshafts serve only to actuate the two fuel injection pumps at each cylinder in unison and at the proper time. The shafts turn at the same rate of speed as the crankshaft.

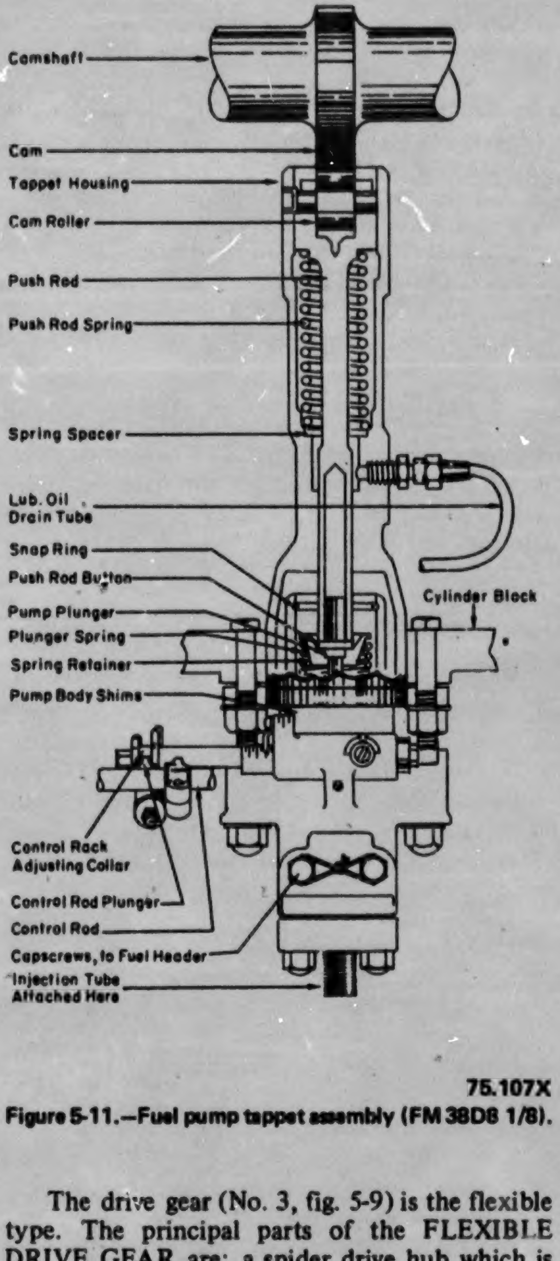
The camshafts for the engine shown in figure 5-9 are of case-hardened alloy steel and are made in sections. The sections are made with match-marked flanges and are joined with fitted bolts. (In some opposed-piston engines made by the same manufacturer, the shafts are the one-piece type.) The cams are an integral part of the shaft and there is one cam on each shaft for each cylinder.

The cams transform the rotary motion of the shaft into the up-and-down motion of the fuel pump plunger, through a tappet assembly attached to the top of the fuel pump body. (See No. 2, fig. 5-9.)

The parts of the tappet assembly are shown in figure 5-11. The push rod spring of the tappet assembly holds the push rod and the cam roller against the camshaft cam. As the camshaft rotates, the cam acts against the cam roller to force the push rod down against the spring tension and actuates the injection pump plunger.

BLOWER DRIVE MECHANISM

The power to drive the blower is transmitted from the upper crankshaft, through a gear train. (See fig. 5-9.) The train consists of a drive gear, a pinion gear, and the two timing (impeller) gears of the blower.

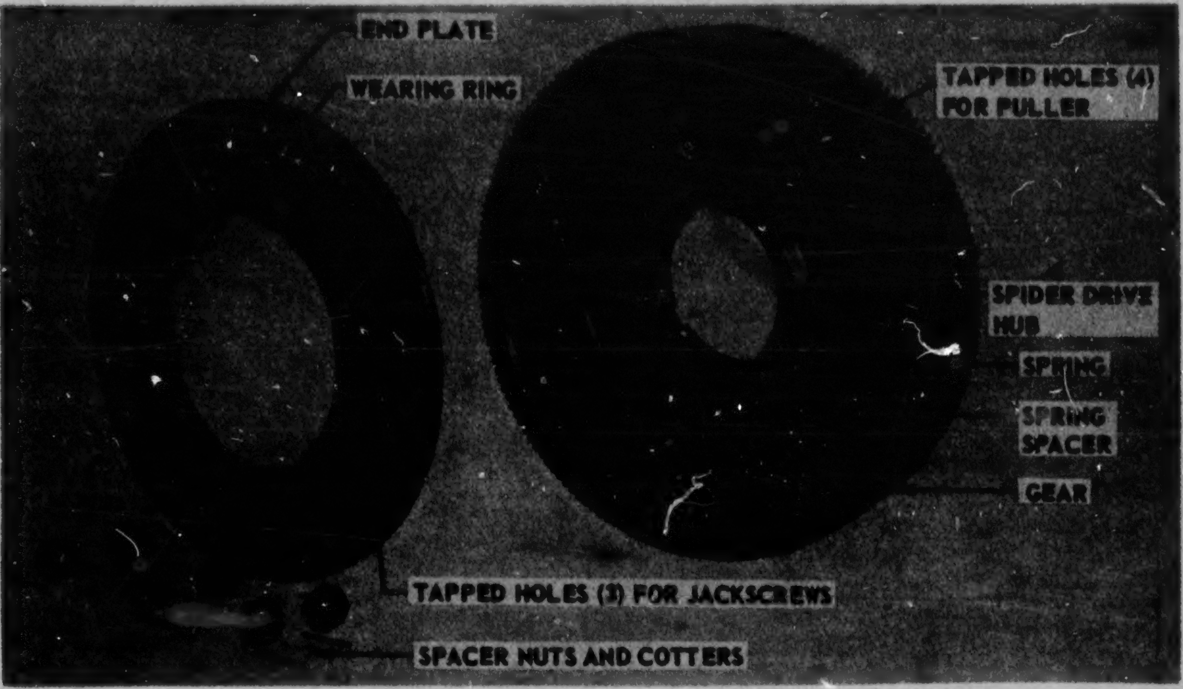

Camshaft
Cam
Tappet Housing
Cam Roller
Push Rod
Push Rod Spring
Spring Spacer
Lub. Oil Drain Tube
Snap Ring
Push Rod Button
Pump Plunger
Plunger Spring
Spring Retainer
Pump Body Shims
Cylinder Block
Control Rack Adjusting Collar
Control Rod Plunger
Control Rod
Capscrews, to Fuel Header
Injection Tube Attached Here

75.107X

Figure 5-11.—Fuel pump tappet assembly (FM 38D8 1/8).

The drive gear (No. 3, fig. 5-9) is the flexible type. The principal parts of the FLEXIBLE DRIVE GEAR are: a spider drive hub which is keyed to the crankshaft, a gear within which spring spacers are bolted, and springs which absorb torsional oscillations transmitted by the crankshaft. A view of the flexible drive gear with end plate removed is shown in figure 5-12.

The flexible drive gear meshes with the drive pinion (No. 4, fig. 5-9). The pinion is keyed to



75.108X

Figure 5-12.—Blower flexible drive gear (FM 38D8 1/8).

the lower impeller shaft and held in place by a locknut. The lower impeller driving (timing) gear (No. 5, fig. 5-9) meshes with the upper impeller driven gear (No. 6, fig. 5-9).

ACCESSORY DRIVE

The majority of the accessories for the FM 38D are driven by a gear mechanism which receives power from the lower crankshaft at the control end of the engine. (See fig. 5-9.) A more detailed view of the accessory drive is shown in figure 5-13. Referring to both these figures as you read the following description will help you to become familiar with the components of the drive and with the way that power is transmitted to the driven units.

The accessory drive transmits power to the water pumps, the fuel oil pump, the lubricating oil pump, and the governor. The drive gear (No. 8, fig. 5-9) of the mechanism is bolted to a flange on the crankshaft. The drive gear is the flexible type, therefore, engine shocks transmitted by the crankshaft are absorbed by the drive springs of the gear.

The water pump drive gears mesh directly with the flexible drive gear. The fuel pump drive gear (attached to the flexible drive gear) transmits power to the fuel pump driven gear through an idler. (See gear on mounting plate, fig. 5-13.) The lubricating oil pump drive gear meshes directly with the flexible drive gear. Power is transmitted to the pump through a shaft and an internal gear coupling–the lubricating oil pump drive. The shaft of the lubricating oil pump drive also transmits power to the governor. A gear on the shaft meshes with a mating gear on the governor drive gear shaft. This shaft drives the governor coupling shaft

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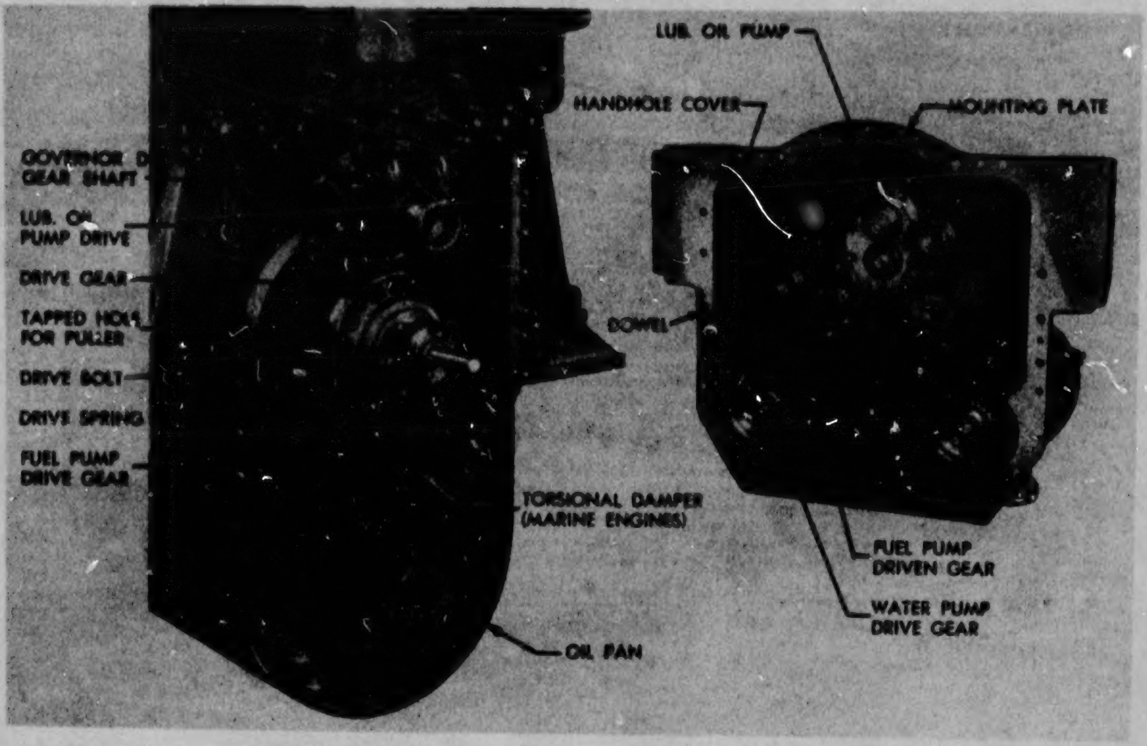

LUB. OIL PUMP
HANDHOLE COVER
MOUNTING PLATE
GOVERNOR D
GEAR SHAFT
LUB. OIL PUMP DRIVE
DRIVE GEAR
TAPPED HOLE FOR PULLER
DRIVE BOLT
DRIVE SPRING
FUEL PUMP DRIVE GEAR
DOWEL
TORSIONAL DAMPER (MARINE ENGINES)
FUEL PUMP DRIVEN GEAR
WATER PUMP DRIVE GEAR
OIL PAN

75.109X

Figure 5-13.—Accessory drive (FM 38D8 1/8).

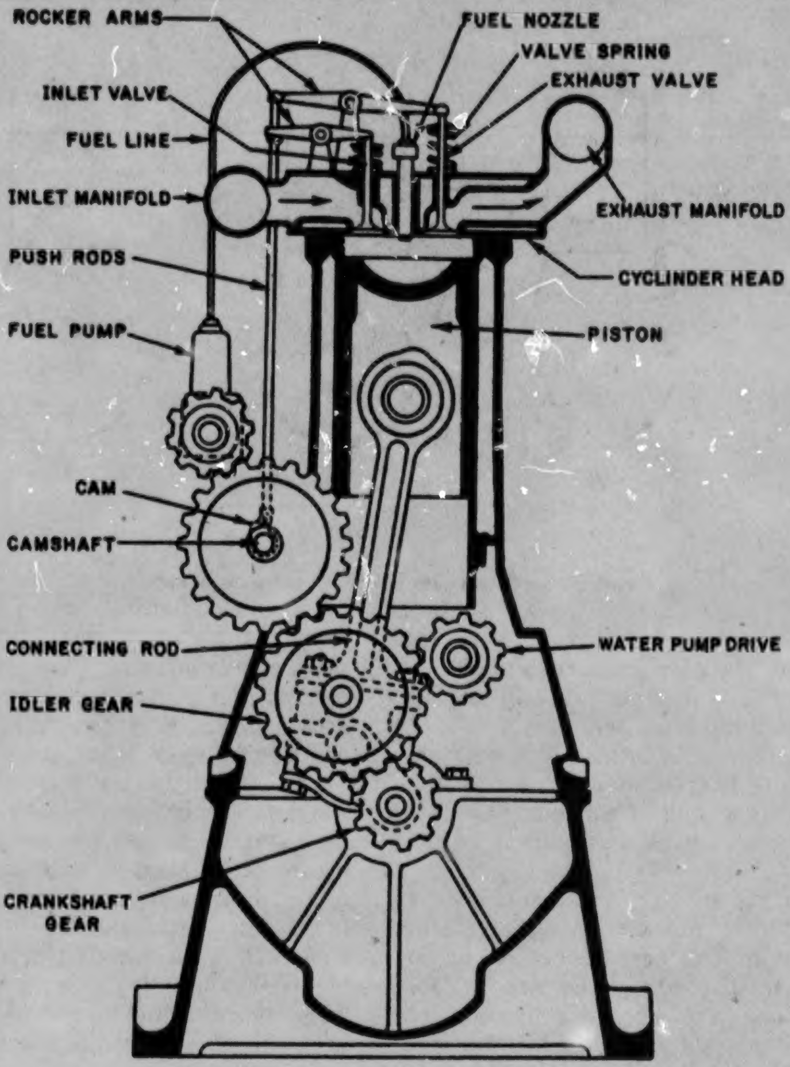
which, in turn, drives the governor, through a bevel gear drive. (See No. 9, fig. 5-9.)

OPERATING MECHANISMS OF A 4-STROKE CYCLE DIESEL ENGINE

The operating mechanisms we have discussed so far have applied to 2-stroke cycle diesel engines. Now we will take a look at the operating mechanisms of a 4-stroke cycle diesel engine. They are similar except for some minor differences in design and arrangement, and the reduced operating speed of the camshaft. The drive has no provision for driving a blower, since 4-stroke cycle diesel engines are either naturally aspirated or are turbocharged. Turbocharging units are exhaust-driven and require no mechanical drive. The valve actuating gear operates valves for both intake and exhaust. The arrangement of the operating mechanism is shown in figure 5-14.

DRIVE MECHANISMS

The 2-stroke cycle engine drive mechanisms considered were either the gear type, chain type, or a combination of both. Very few chain type drives are used on 4-stroke cycle engines by the Navy; therefore, we will discuss only the gear type drives. The primary drive which takes power from the crankshaft is a gear assembly or gear train. The arrangement of the gear train which forms the drive will vary according to the engine.


ROCKER ARMS
FUEL NOZZLE
VALVE SPRING
EXHAUST VALVE
INLET VALVE
FUEL LINE
INLET MANIFOLD
EXHAUST MANIFOLD
PUSH RODS
CYCLINDER HEAD
FUEL PUMP
PISTON
CAM
CAMSHAFT
CONNECTING ROD
WATER PUMP DRIVE
IDLER GEAR
CRANKSHAFT GEAR

75.238

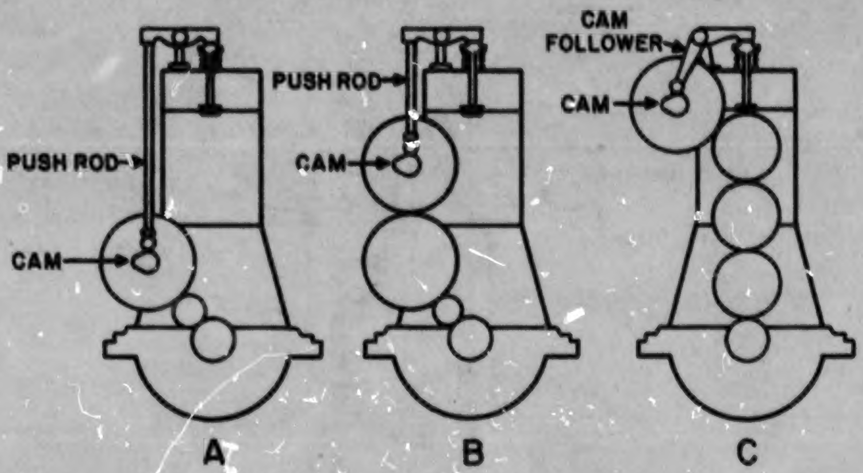
Figure 5-14.—Arrangement of 4-cycle diesel engines.

Valve Actuating Gear

In addition to furnishing power for the various engine accessories, the drive mechanism provides the power that operates the engine valves. The basic job of the valve actuating gear is both to cause and to control the opening and closing of the inlet and exhaust valves.

In most engines, this gear consists of (1) rocker arms that actuate the valves, (2) push rods that connect the rocker arms and the cams on the camshaft, and (3) a drive that connects the camshaft to the crankshaft.

CAMSHAFT DRIVES.–In 4-stroke cycle diesel engines the camshaft speed must be exactly one-half the crankshaft speed, so the camshaft makes one complete revolution while the crankshaft makes two. Because these speed relations must be exact, the connecting drive



75.239

Figure 5-15.—Cam location 4-stroke cycle diesel engine.

must be positive. The drive arrangement used for any particular engine depends to a large extent on where the camshaft is located.

The camshaft may be located low, near the crankshaft, using long push rods, or on the cylinder block using short push rods, or at the cylinder head level without push rods. (See fig. 5-15.)

The gears of the drive must be accurately cut and heat treated to resist wear. Helical teeth (teeth placed at an angle) are frequently used in place of spur teeth (teeth placed straight) for greater quietness and more transmission of power. Gears and shafts are used in various arrangements to drive the vital components and accessories of the engine.

Camshafts.—The camshafts in 4-stroke cycle diesel engines carry the cams for actuating the inlet and exhaust valves. In addition, the camshaft may carry cams for fuel injection pumps, fuel-spray valves, or air starting valves. Some engines have two camshafts, some have one, depending on engine design.

The camshaft may be constructed in several ways. It can be forged in one piece, including the cams themselves, as integral cams. It may consist of a steel shaft with separate forged-steel or cast-iron cams keyed on to the shaft. Very few of the latter are still in service. Another construction, used on large engines, is to make up the camshaft in sections. Each section handles one cylinder, and enough sections are bolted together to handle the whole engine.

Valve Gear in Cylinder Head.—The remaining parts of the valve actuating gear and the valves are mounted in the cylinder head. The various parts which are mounted in the head were covered in chapter 4 of this manual.

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CHAPTER 6

DIESEL ENGINE AIR SYSTEMS

Combustion requires air, fuel, and heat; certain amounts of all three are necessary if an engine is to operate. This chapter deals only with AIR as required to support combustion in the cylinder of an engine. The processes of scavenging and supercharging are considered as well as the group of parts involved in supplying the cylinders of an engine with air and in removing the waste gases after combustion and the power event are finished. The engine parts which accomplish these functions are commonly referred to as the INTAKE EXHAUST systems.

INTAKE SYSTEMS

This section deals with intake systems of diesel engines only; nevertheless, much of the information dealing with the parts of diesel engine air systems is also applicable to most of the parts in similar systems of gasoline engines.

Although the primary function of a diesel engine intake system is to supply the air required for combustion, the system also cleans the air and reduces the noise created by the air as it enters the engine. An intake system may include an air silencer, an air cleaner and screen, an air box or header, intake valves or ports, a blower, an air heater, and an air cooler. Not all of these parts are common to every intake system. An intake system for one type of high-speed diesel engine, which provides a clean supply of air with minimum noise to the combustion spaces, is shown in cross section in figure 6-1.

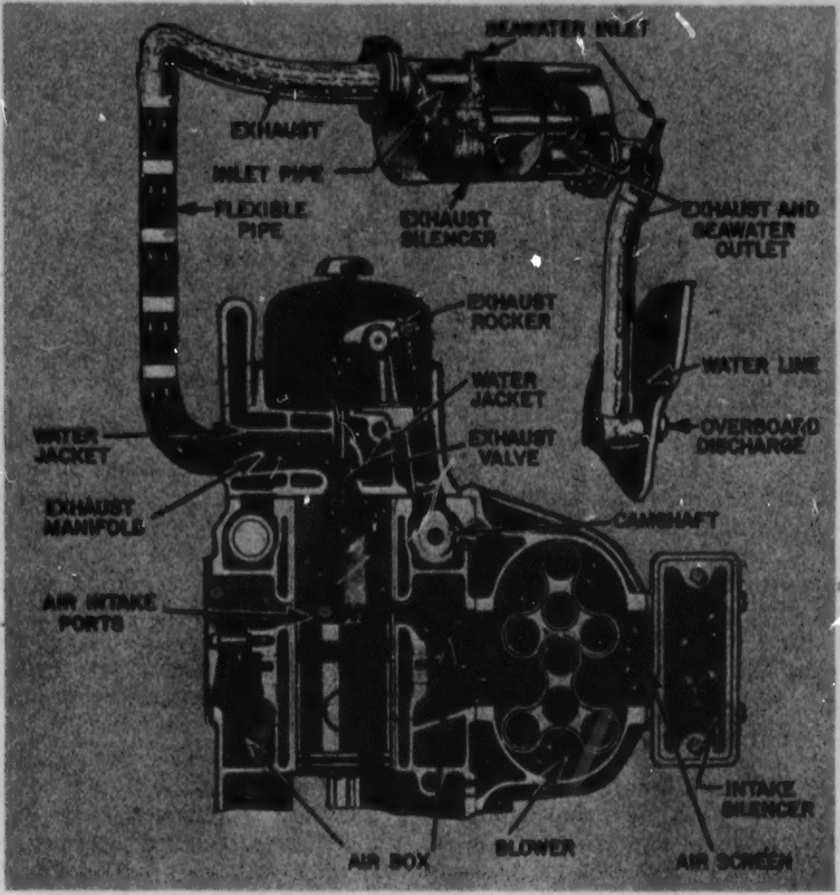
SCAVENGING AND SUPERCHARGING

In the intake systems of all 2-stroke cycle diesel engines and some 4-stroke cycle diesel engines, a device, usually a blower, is installed to increase the flow of air into the cylinders. The blower compresses the air and forces it into an air box or manifold which surrounds or is attached to the cylinders of an engine. Thus, an increased amount of air under constant pressure is available as required during the cycle of operation.

The increased amount of air, a result of blower action, is used to fill the cylinder with a fresh charge of air. During the process, the increased amount of air helps to clear the cylinder of the gases of combustion. The process is called scavenging. Therefore, the intake system of some engines, especially those operating on the 2-stroke cycle, is sometimes called the scavenging system. The air forced into the cylinder is called scavenge air, and the ports through which it enters are called scavenge ports.

Scavenging must take place in a relatively short portion of the operating cycle; the duration of the process differs in 2- and 4-stroke cycle engines. In a 2-stroke cycle engine, the process takes place during the latter part of the downstroke (expansion) and the early part of the upstroke (compression). In a 4-stroke cycle engine, scavenging takes place when the piston is nearing and passing TDC during the latter part of an upstroke (exhaust) and the early part of a downstroke (intake). The intake and exhaust openings are both open during this interval of time. The overlap of intake and exhaust permits the air from the blower to pass through the cylinder into the exhaust manifold, cleaning out the exhaust gases from the cylinder and, at the same time, cooling the hot engine parts.

When scavenging air enters the cylinder of an engine, it must be so directed that the waste


SEAWATER INLET
EXHAUST
INLET PIPE
FLEXIBLE PIPE
EXHAUST SILENCER
EXHAUST AND SEAWATER OUTLET
EXHAUST ROCKER
WATER LINE
WATER JACKET
EXHAUST VALVE
OVERBOARD DISCHARGE
WATER JACKET
EXHAUST MANIFOLD
CAMSHAFT
AIR INTAKE PORTS
INTAKE SILENCER
AIR BOX
BLOWER
AIR SCREEN

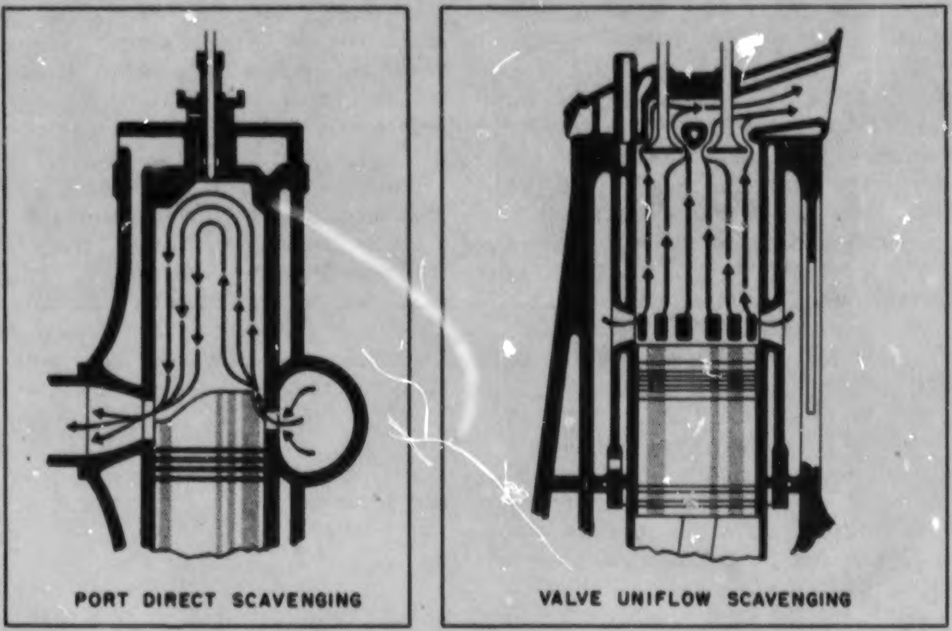
75.151X

Figure 6-1.—Air systems of a 2-stroke cycle engine (GM 71).

gases are removed from the remote parts of the cylinder. The two principal methods by which this is accomplished are sometimes referred to as PORT scavenging and VALVE scavenging. Port scavenging may be direct (cross flow), loop (return), or uniflow type. (See fig. 6-2.)

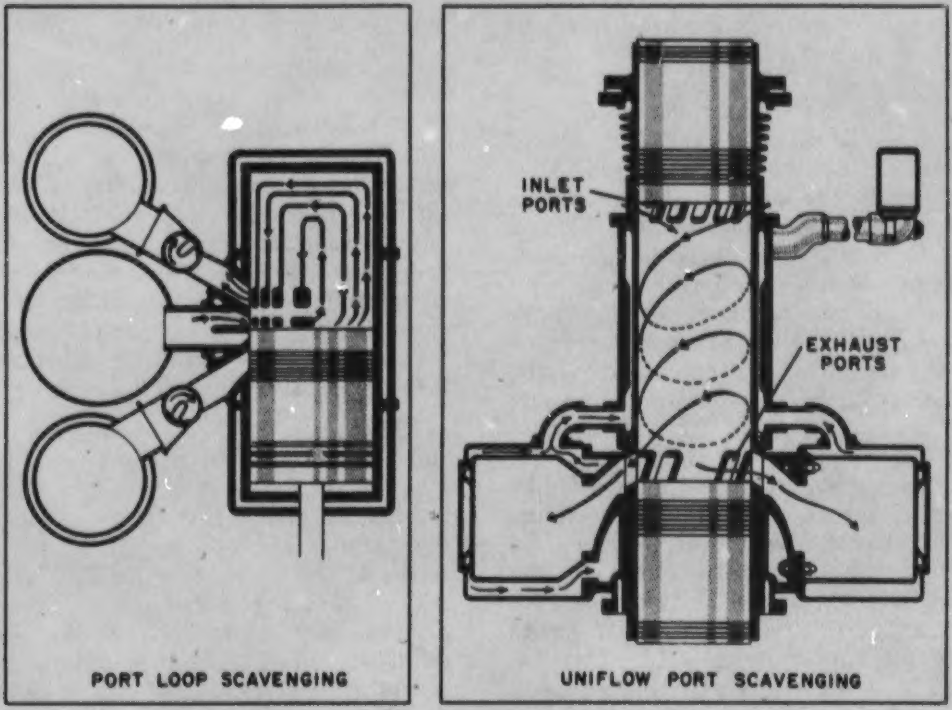
Scavenging and supercharging are not common to all diesel engines. For instance, in some 4-stroke cycle engines, the air enters the cylinder as a result of a pressure difference created by the piston as it moves away from the combustion space during the intake event. This type of intake is sometimes referred to as the "suction" type, or naturally aspirated intake; however, the air is actually forced into the cylinder because of the greater pressure outside the cylinder.

An increase in air flow into cylinders of an engine can be used to increase power output, in addition to being used for scavenging. Since the power of an engine comes from the burning of fuel, an increase in power requires more fuel; the increased fuel, in turn, requires more air, since each pound of fuel requires a certain amount of air for combustion. The supplying of more air to the combustion spaces than can be supplied through the action of atmospheric pressure and piston action (in 4-stroke cycle engines) or



PORT DIRECT SCAVENGING

VALVE UNIFLOW SCAVENGING


INLET
PORTS
EXHAUST
PORTS

PORT LOOP SCAVENGING

UNIFLOW PORT SCAVENGING

75.152

Figure 6-2.—Methods of scavenging in diesel engines.

scavenging air (in 2-stroke cycle engines) is called supercharging.

In some 2-stroke cycle diesel engines, the cylinders are supercharged during the air intake simply by increasing the amount and pressure of scavenge air. The same blower is used for supercharging and scavenging. Scavenging is done when air is admitted under low pressure into the cylinder while the exhaust valves or ports are open. Supercharging is done with the exhaust ports or valves closed, which enables the blower to force air under pressure into the cylinder and thereby increase the amount of air available for combustion. The increase in pressure, resulting from the compressing action of the blower, will depend on the type of installation, but it is usually low, ranging from 1 to 5 psi. With the increase in pressure and amount of air available for combustion, there is a corresponding increase in combustion efficiency within the cylinder. In other words, a given size engine which is supercharged can develop more power than the same size engine which is not supercharged.

To supercharge a 4-stroke diesel engine, a blower must be added to the intake system since exhaust and intake in an unsupercharged engine are performed by the action of the piston. The timing of the valves in a supercharged 4-stroke cycle engine is also different from that in a similar engine which is not supercharged. In the supercharged engine the closing of the intake valve is slowed down so that there is considerable overlap of the intake and exhaust events. The overlap increases power; the amount of the increase depends on the supercharging pressure. The increased overlap of the valve openings also permits the air pressure created by the blower to remove gases from the cylinder during the exhaust event. Study figure 6-3 (foldout at end of chapter) so that you understand how the opening and closing of the intake and exhaust valves, or ports, affect both scavenging and supercharging. Also, note the differences in these processes as they occur in supercharged 2- and 4-stroke cycle engines.

In figure 6-3, the circular pattern represents crankshaft rotation. Some of the events occurring in the cycles are shown in degrees of shaft rotation for purposes of illustration and easier comparison only. (When dealing with the timing of a specific engine, check the appropriate instructions.)

In studying figure 6-3, keep in mind that the crankshaft of a 4-stroke cycle engine makes two complete revolutions in one cycle of operation while the shaft in a 2-stroke cycle engine makes only one revolution per cycle. Also, keep in mind that the exhaust and intake events in a 2-stroke engine do not involve complete piston strokes as they do in a 4-stroke engine.

Four-Stroke Cycle Scavenging and Supercharging

Part A of figure 6-3 is based on operation of a 4-stroke cycle engine using a centrifugal type blower (turbocharger) to supply the cylinders with air under pressure.

In a supercharged 4-stroke cycle engine, the duration of each event differs somewhat from the length of the same events in a nonsupercharged 4-stroke engine. The intake and exhaust valves are open much longer in a supercharged engine, and the compression and power events are shorter, permitting a longer period for scavenging. When the exhaust event is completed, the turbocharger fills the cylinder with fresh air under pressure before the compression event begins; in other words, the turbocharger supercharges the cylinders.

To understand the relationship of scavenging and supercharging to the events of the cycle, look again at part A in figure 6-3 and follow through the complete cycle. Start your study of the cycle at TDC, the beginning of the power event. At this point, peak compression has been reached, fuel injection is nearly completed, and combustion is in progress. Power is delivered during the downstroke of the piston for 125° of crankshaft rotation. At this point in the downstroke (55° before BDC) the power event ends and the exhaust valves open.

The exhaust valves remain open throughout the rest of the downstroke (55°), throughout all

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of the next upstroke (180°), and throughout 85° of the next downstroke; a total of 320° of shaft rotation. At a point 75° before the piston reaches TDC the intake valves open and the turbocharger begins forcing fresh air into the cylinder. For 160° of shaft rotation, the air passes through the cylinder and out the exhaust valves, clearing the waste gases from the cylinder. The rapid flow of gases escaping through the exhaust manifold drives the turbocharger. The process of scavenging continues until the exhaust valves close at 85° past TDC.

The intake valves remain open, after the exhaust valves close, for an additional 140° of shaft rotation (45° past BDC). From the time the exhaust valves close until the piston reaches approximately BDC, the cylinder is being filled with air from the blower. During this interval, the increase in pressure is too small to consider because of the increasing volume of the cylinder space (the piston is in downstroke). However, when the piston reaches BDC and starts the upstroke, the volume of the space begins to decrease as the blower continues to force air into the cylinder. The result is a supercharging effect with the pressure reaching 3 to 5 psi by the time the intake valves close.

During the remainder of the upstroke (after the intake valves close) the supercharged air is compressed. Fuel injection begins several degrees before TDC and ends shortly after TDC. The actual length of the injection period in a specific engine depends on the engine's speed and load. When the piston reaches TDC, a cycle (two complete crankshaft revolutions and four strokes of the piston) has taken place, and the engine is ready to repeat the cycle.

Two-Stroke Cycle Scavenging and Supercharging

In comparing parts A and B of figure 6-3, note that the length of the supercharging and scavenging periods in a 2-stroke cycle engine is not the same as in a 4-stroke cycle engine. Also, there is considerable difference in piston location between the times when these processes take place in the two types of engines. In a 4-stroke cycle, scavenging takes place while the piston is traveling through the latter part of the upstroke and the early part of the downstroke, and supercharging takes place when the piston is in the vicinity of BDC. In a 2-stroke cycle, the processes of scavenging and supercharging both take place while the piston is in the lower part of the cylinder. A piston in a 4-stroke cycle engine does much of the work of intake and exhaust, but in a 2-stroke cycle engine the piston does very little work in these two processes. Because of this, many 2-stroke cycle engines use a blower to force air into the cylinder and to clear out the exhaust gases.

Part B of figure 6-3 is based on the operating cycle of the engine shown in figure 6-1. If you compare part B with part A (fig. 6-3), the differences in the scavenging and supercharging processes in 2- and 4-stroke cycle engines are more apparent. Start your study of the cycle with the piston at TDC (part B of fig. 6-3). Fuel has been injected, ignition has occurred, and combustion is taking place. The power developed forces the piston through the power event until the piston is 92 1/2° (as compared to 125° for the 4-stroke cycle in the preceding example) past TDC, just a little more than halfway through the downstroke. At this point, the exhaust valves open, gases escape through the manifold, and cylinder pressure drops rapidly.

When the piston reaches a point 48° before BDC, the intake ports are uncovered as the piston moves downward and scavenging begins. (Compare this with the opening of the intake valves in a 4-stroke cycle.) The scavenging air, under blower pressure, swirls upward through the cylinder and clears the cylinder of exhaust gases. The situation in the cylinder when scavenging starts is approximately the same as that illustrated in figure 6-1 and in figure 6-2 part B. Note the position of the piston, the open scavenging ports, the open exhaust valves, and the flow of air through the cylinder. The flow of scavenge air through the cylinder also helps to cool the parts which are heated by combustion.

Scavenging continues until the piston is 44 1/2° past BDC (a total of 92 1/2° as compared with 160° in the 4-stroke cycle) at which point the exhaust valves close. The exhaust valves remain open during only 132°, as compared with the 320° in the 4-stroke cycle. The scavenge ports remain open for another 3 1/2° of shaft rotation (45° in the 4-stroke cycle), and the blower continues to force air into the cylinder. Even though the ports are open for only a short interval after the exhaust valves close, enough time is available for the blower to create a supercharging effect before the compression event starts.

The piston closes the intake ports at 48° past BDC. The compression event takes place during the remainder of the upstroke with injection and ignition occurring at TDC. At this point one cycle is ended and another is ready to start.

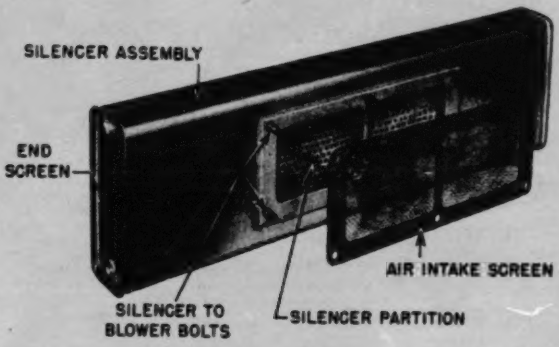
INTAKE SYSTEM COMPONENTS

There are many variations in the design of the engine parts which function, as a group, to properly direct clean air to intake valves or ports. Regardless of design differences, the function of each kind of part remains the same. We cannot cover every type or model of each part of engine air intake systems in this course. Therefore, we shall discuss only a few of the common types of each of the principal parts of these systems.

Silencers, Screens, and Cleaners

Air must enter the intake system as quietly and as clean as possible. A diesel engine uses a great quantity of air. Unless a silencer is installed, air will rush through the air-cleaning devices sounding like an extremely high-pitched whistle. Silencers are generally constructed as part of the air-cleaning components.

One type of air-intake silencer assembly is shown in figure 6-4. This type of silencer is used on some models of Gray Marine and GM 71 engines.



75.154X

Figure 6-4.—Air-intake silencer assembly (GM 71).

The silencer assembly is bolted to the intake side of the blower. (See fig. 6-1.) A perforated steel partition divides the silencer lengthwise into two sections. Air enters the end of the silencer and passes through the inner section into the blower. The noise of the air passes through the silencer where it is reduced by a sound-absorbent, flameproof, felted cotton waste which fills the outer section of the silencer.

Upon leaving the silencer, the air enters the blower through an air-intake screen. (See figs. 6-1 and 6-4.) The air-intake screen prevents particles of foreign material from entering the engine. Unless foreign material is filtered from the intake air, it might seriously damage the blower assembly and internal engine parts such as pistons, piston rings, and liners.

The silencer-and-screen assembly just described is sometimes referred to as a DRY-type cleaner and silencer. Another type of air cleaner and silencer is the VISCOUS-type. In both dry and viscous types, intake air is drawn through a fine mesh or screen which filters the air. The mesh of such cleaners may consist of cotton fabric, wire screening, specially wound copper crimp, or metal wool. The principal difference between cleaners of the dry and viscous types is that the mesh of a viscous type cleaner is wet, usually, with a medium weight oil. An air cleaner and silencer assembly of the

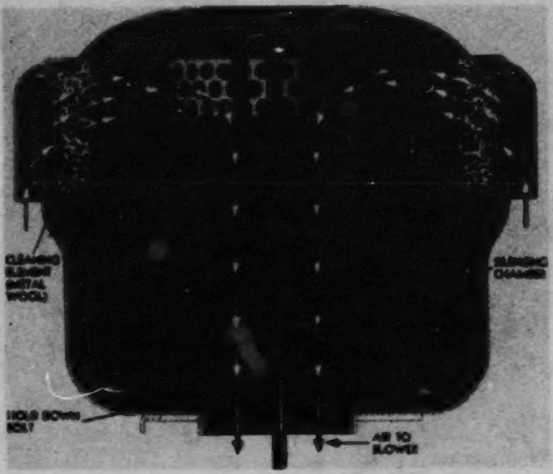


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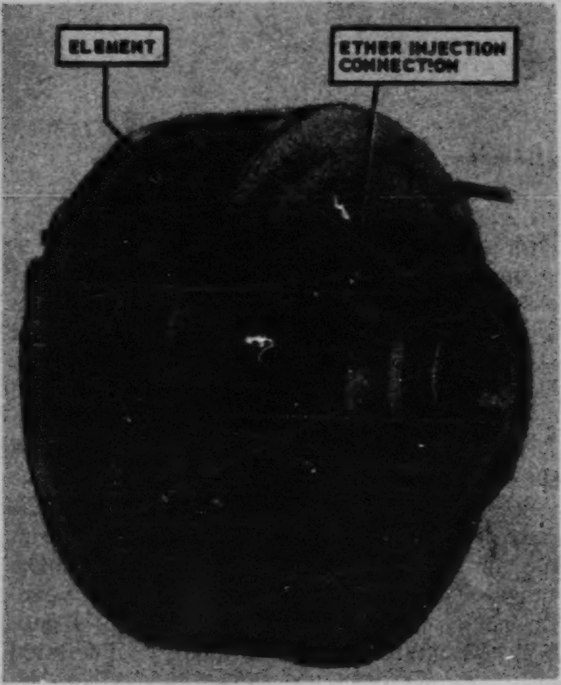
Figure 6-5.—Viscous-type air silencer and cleaner (GM 71).



75.156
Figure 6-6.—Air filter and silencer.

viscous type is shown in figure 6-5. The cleaning element (metal wool in the example shown) is oil-soaked to collect the dust and dirt from the air passing through the assembly. The hollow housing which supports the element also acts as a silencing chamber. This type assembly is used on some models of Gray Marine and GM 71 engines.

The assembly shown in figure 6-6 is another viscous-type cleaner and silencer. The filter and silencer of this unit form a cylinder silencing chamber, the ends of which are packed with sound-deadening material. Air enters the silencer through the circumferential surface of the silencing chamber. The filter element fits over the air inlet. The element of the filter consists of a series of oil-wetted wire baffles which collect any airborne dirt entering the chamber.

Another type of intake-air cleaner and silencer includes an oil bath as part of the assembly. A cross section of an oil bath air cleaner is shown in figure 6-7.

In oil bath cleaners, the intake air strikes the oil before passing through the mesh. The inertia of the airborne dust particles causes some of them to strike and adhere to the oil surface. The mesh collects particles which are not removed by the oil.

Note the similarity between the oil bath filter in figure 6-7 and the viscous-type cleaner shown in figure 6-5. The principal difference is that the oil bath cleaner has an oil reservoir which traps the major portion of the dirt entering the system.

The silencer and cleaner assemblies described in the preceding paragraphs are representative of the devices used to clean intake air and to reduce the noise it makes as it enters the engine. To ensure sufficient cleaning of the intake air, air filters, regardless of type, should be cleaned as specified by the Planned Maintenance System.

Blowers

Blowers are necessary on most 2-stroke cycle engines to force scavenging air through the

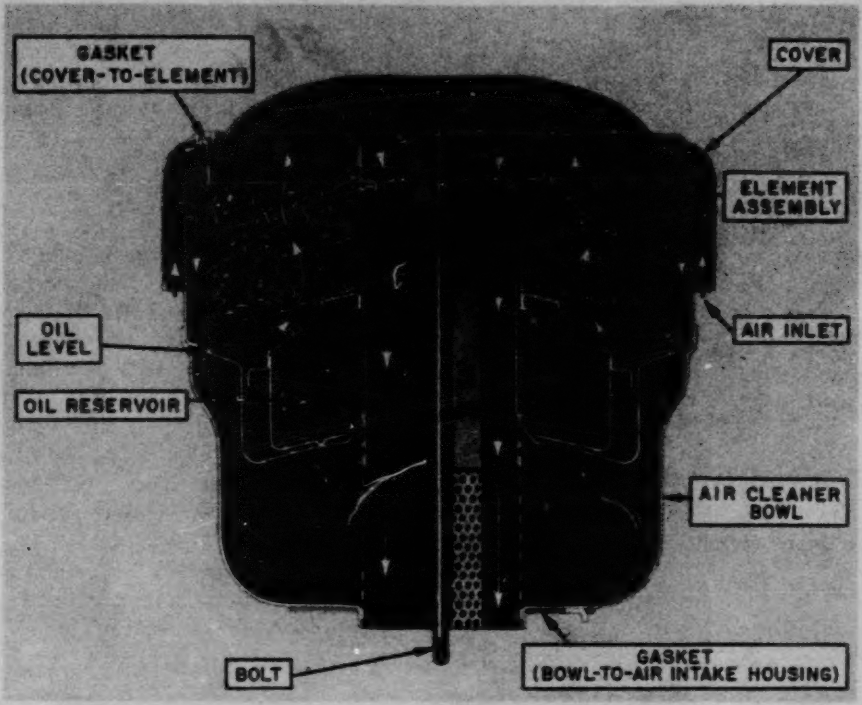


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Figure 6-7.—Oil bath air cleaner and silencer assembly (GM 71).

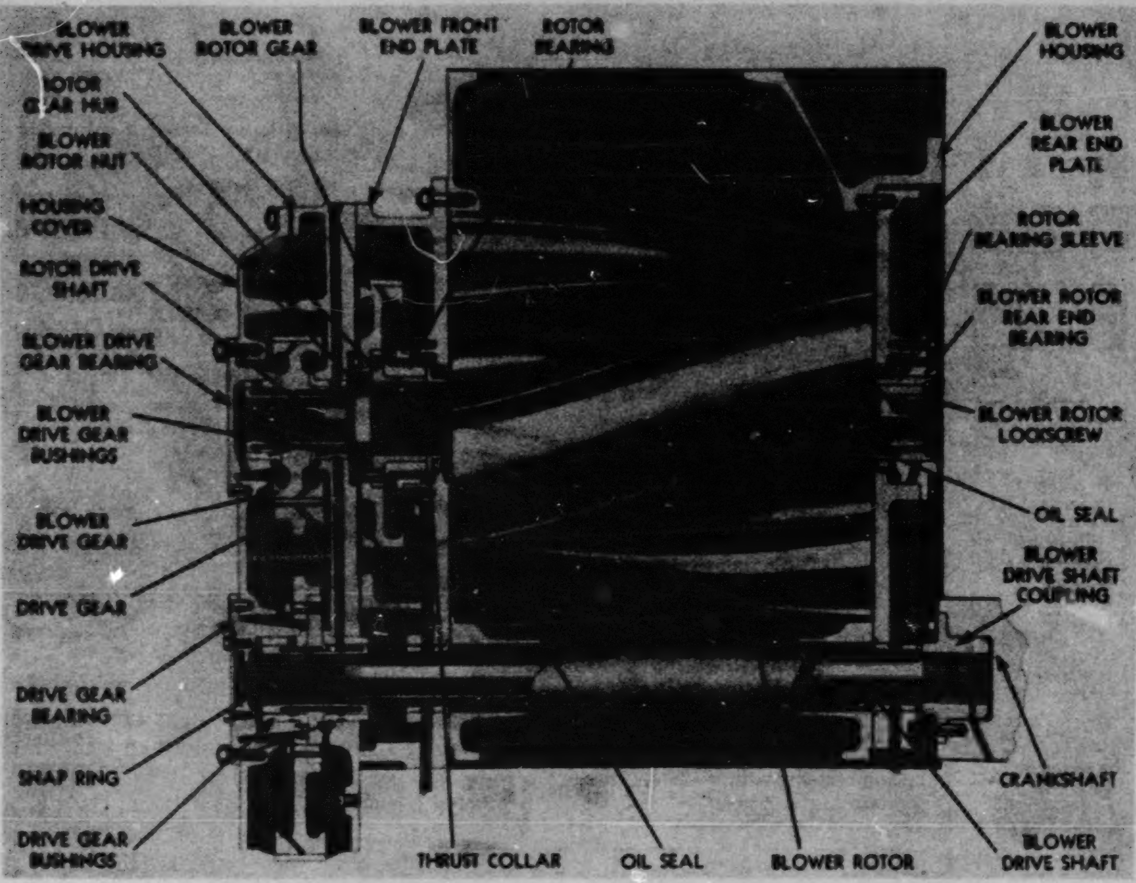
cylinders. In addition, a supercharged engine, either 2- or 4-stroke cycle, must have a blower to fill the cylinder with fresh air at a pressure above atmospheric pressure before the compression event starts. Basically, the primary function of an engine blower is to deliver a large volume of air at a low pressure (1 to 5 psi).

There are two principal types of blowers: POSITIVE DISPLACEMENT and CENTRIFUGAL. A positive displacement blower is usually gear-driven directly by the engine, while a centrifugal blower is usually driven by an exhaust-gas turbine. Positive displacement blowers may be divided into two groups: the multiple-lobe type, commonly called the LOBE, or Roots, blower; and the AXIAL-FLOW, or Whitfield blower.

Blowers are introduced briefly in *Fireman*, NAVEDTRA 10520-E. Since there are many variations in blower designs, we shall discuss examples of the more common designs. The first example, a lobe blower, is commonly used on many 2-stroke cycle engines. The other examples are exhaust-driven centrifugal type blowers (turbochargers) found on some 4-stroke cycle diesel engines.

The cross section of the blower in figure 6-8 shows the many parts of one design of a positive displacement, lobe-type, rotary blower. The drive mechanism, which transmits power from the crankshaft to the blower, is attached to the end of the blower. (Drive mechanisms are discussed in chapter 5 of this manual.) Figure 6-9 is an external view of the blower illustrated in figure 6-8 (rotors are being removed from the housing). Blowers of this general type are commonly found on General Motors, Gray Marine, and many other engines.

The blower illustrated has two 3-lobe rotors which rotate in opposite directions within the


BLOWER DRIVE HOUSING
BLOWER ROTOR GEAR
BLOWER FRONT END PLATE
ROTOR BEARING
BLOWER HOUSING
ROTOR GEAR HUB
BLOWER ROTOR NUT
HOUSING COVER
ROTOR DRIVE SHAFT
BLOWER DRIVE GEAR BEARING
BLOWER DRIVE GEAR BUSHINGS
BLOWER DRIVE GEAR
DRIVE GEAR
DRIVE GEAR BEARING
SNAP RING
DRIVE GEAR BUSHINGS
BLOWER REAR END PLATE
ROTOR BEARING SLEEVE
BLOWER ROTOR REAR END BEARING
BLOWER ROTOR LOCKSCREW
OIL SEAL
BLOWER DRIVE SHAFT COUPLING
CRANKSHAFT
BLOWER DRIVE SHAFT
THRUST COLLAR
OIL SEAL
BLOWER ROTOR

75.158X

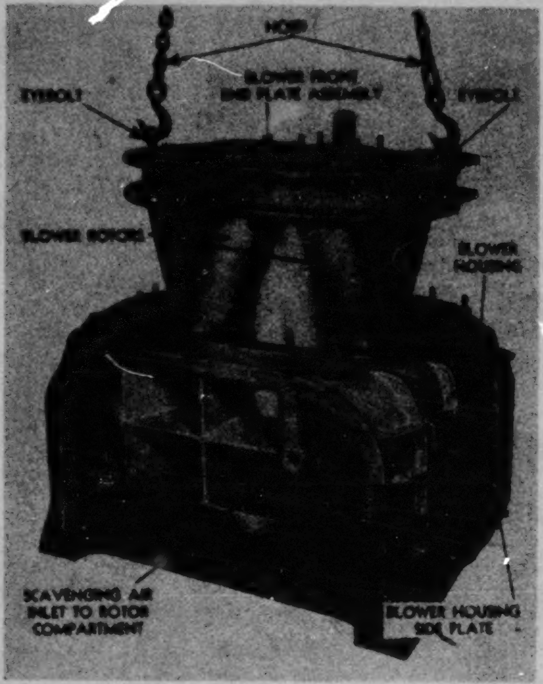
Figure 6-8.—Cross section of a positive displacement blower (GM 12- and 16-278A).

closely fitted, inner wall of the housing. The rotors do not touch each other or the housing wall which surrounds them. The rotors are mounted on tubular, serrated shafts to which the helical rotor gears are attached. (See fig. 6-10.)

The closely fitted rotor gears are rigidly attached to the shafts and are timed to keep the meshing lobes of the rotors from touching. The radial position of each rotor and the clearance between the rotor lobes and the housing are maintained by babbitted bearings located in the blower end plates. The rotor bearings at the gear end have thrust surfaces which maintain the correct axial position of the rotors and prevent contact between the rotors and the end plates. (See fig. 6-8.)

Oil passages in the end plates (fig. 6-8) conduct lubricating oil, under pressure to the bearings. Oil seals are provided at each bearing to prevent oil from entering the housing.

An airtight seal is maintained between the end plates and the housing by a fine silk thread and a very thin coat of nonhardening gasket compound. This material is placed around the

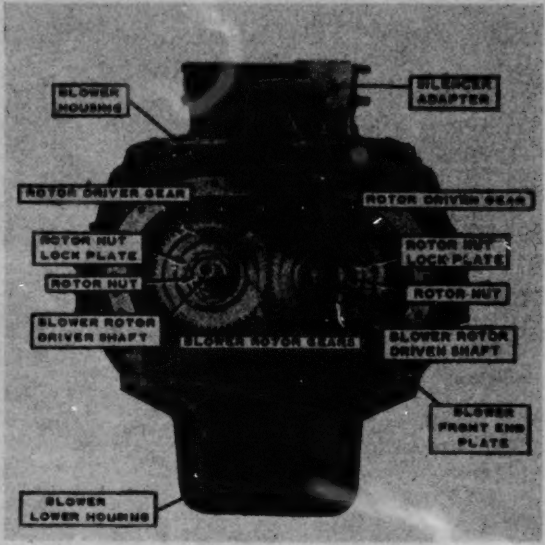

HOIST
EYEBOLT
BLOWER FRONT END PLATE ASSEMBLY
EYEBOLT
BLOWER ROTORS
BLOWER HOUSING
SCAVENGING AIR INLET TO ROTOR COMPARTMENT
BLOWER HOUSING SIDE PLATE

75.159X
Figure 6-9.—Positive displacement blower—rotors and housing (GM 12- and 16-278A).

housing end-plate openings, inside the stud line. (See line of studs in fig. 6-9.)

Power to drive the blower is transmitted from the blower-and-accessory drive mechanism (attached to the front of the blower) to the rotor gear train (fig. 6-10) by a shaft which extends through passage in the blower housing. (See fig. 6-8.)

Air from the silencer enters the top of the blower housing through the scavenging air inlet. (See fig. 6-9.) The rotor lobes produce a continuous and uniform displacement of air. The lobes carry the air around the cylindrical sides of the housing (in the spaces between the lobes and the housing) and force the air, under pressure, to the bottom of the housing. An opening in the inner wall of the housing permits the air to pass into the space between the inner and outer walls of the housing, and then out the discharge opening.


BLOWER HOUSING
SILENCER ADAPTER
ROTOR DRIVER GEAR
ROTOR DRIVEN GEAR
ROTOR NUT LOCK PLATE
ROTOR NUT LOCK PLATE
ROTOR NUT
ROTOR NUT
BLOWER ROTOR DRIVER SHAFT
BLOWER ROTOR GEARS
BLOWER ROTOR DRIVEN SHAFT
BLOWER FRONT END PLATE
BLOWER LOWER HOUSING

75.160X
Figure 6-10.—Blower rotor gear train (GM 12- and 16-278A).

Unlike positive displacement blowers, which are driven through a gear train by the engine crankshaft, the centrifugal type blower, or turbocharger, takes its power from the exhaust gases, thereby using some of the energy that would otherwise be wasted. In brief, the principle of operation of a turbocharger is as follows: (1) the gases from the exhaust manifold drive a turbine, and (2) the turbine drives an impeller (on the same shaft), which supplies air to the cylinders for scavenging and supercharging. The several types of centrifugal blowers in naval service all operate on this basic principle.

Some of the turbochargers installed on marine engines used by the Navy are the Airesearch, Alco-Buchi, the Elliot-Buchi, and the General Electric. Even though all these blowers operate on the same principle and are somewhat similar in appearance, there are notable differences in the construction of the various types. Some of the main differences between the Alco-Buchi and the Elliot-Buchi turbochargers are given in figure 6-11.

Figure 6-12 shows a phantom view of the Alco-Buchi turbocharger and figure 6-13 shows

ALCO-BUCHI	ELLIOTT-BUCHI
LUBRICATED BY OIL FROM THE ENGINE LUBRICATING SYSTEM.	INDEPENDENTLY LUBRICATED BY OIL FROM A SEPARATE TURBOCHARGER OIL TANK. THE OIL PUMP IS USUALLY DRIVEN BY THE TURBOCHARGER.
IMPELLER AND TURBINE ARE LOCATED ON THE SHAFT BETWEEN THE TWO SHAFT BEARINGS.	BOTH SHAFT BEARINGS ARE LOCATED ON THE SAME SIDE OF THE OVERHUNG TURBINE WHEEL.
LABYRINTH RING SEALS ARE LOCATED BETWEEN THE SHAFT AND THE CASING AND BETWEEN THE IMPELLER AND THE CASING.	LABYRINTH RING SEAL IS LOCATED BETWEEN THE IMPELLER AND THE CASING.
MACHINED, SHAFT BEARING END-FACES SERVE AS THRUST BEARINGS. STEEL THRUST COLLAR AND WASHER, ON THE TURBINE END OF THE SHAFT, LIMIT LONGITUDINAL MOVEMENT OF THE SHAFT.	STEEL THRUST COLLAR, KEYED TO THE SHAFT AND WORKING BETWEEN THE MACHINED END-FACE ON THE OUTER SHAFT BEARING AND THE THRUST BEARING FACE, LIMITS LONGITUDINAL MOVEMENT OF THE SHAFT.
BLOWER CASE IS SPLIT HORIZONTALLY.	BLOWER CASE IS DIVIDED VERTICALLY, PERPENDICULAR TO THE CENTER LINES OF THE SHAFT.

75.161

Figure 6-11.—Construction differences in turbochargers.

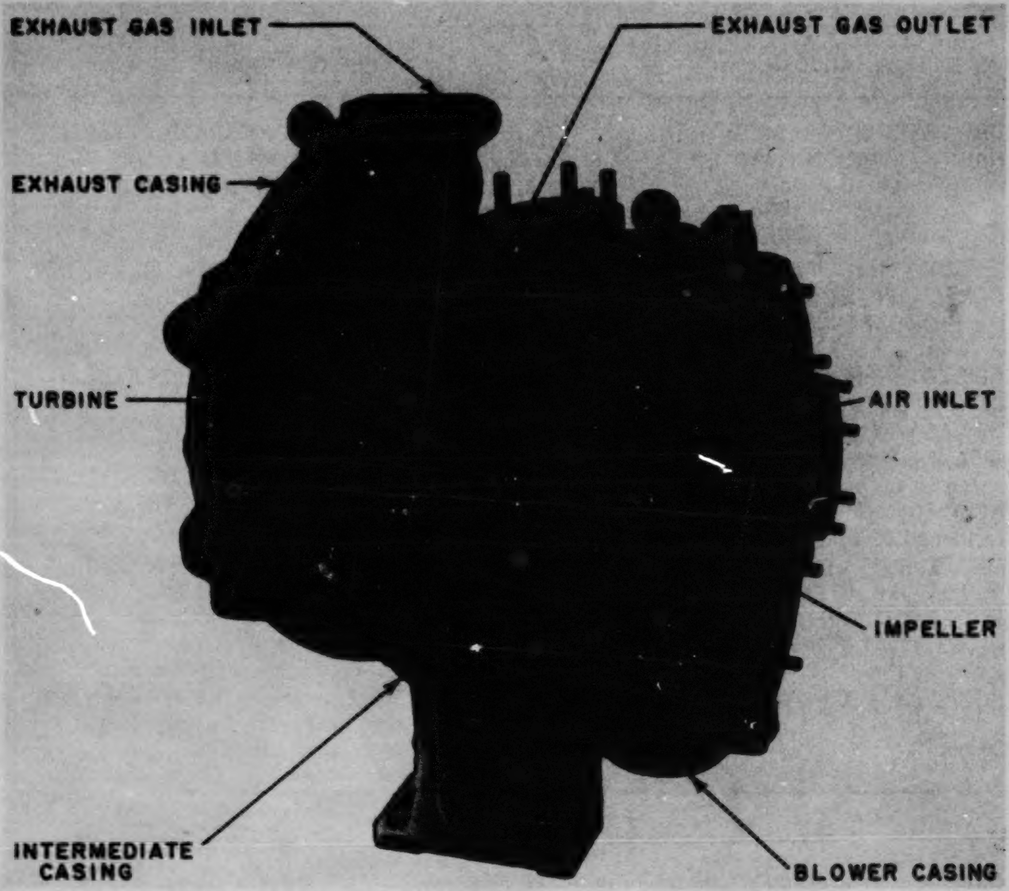
two views of the Elliot-Buchi turbocharger. Figure 6-14 shows a cutaway view of the General Electric turbocharger.

Two of the turbochargers mentioned, the Elliot-Buchi and the General Electric, are described later in some detail as examples of the devices used to supercharge 4-stroke cycle engines.

Many of the parts of an Elliot-Buchi turbocharger are identified in figures 6-13 and 6-14. You can see different views of some of the parts by looking at both figures. As you study the following description, frequent reference to figures 6-13 and 6-14 will help you to become familiar with the turbocharger and its operation.

In the discussion we will consider this turbocharger as being divided into four systems: exhaust, intake, cooling, and lubricating. Similar systems are common to other exhaust-driven turbochargers.

EXHAUST SYSTEM.–The exhaust system consists of an impulse turbine inside a turbine casing. The system furnishes the driving power for the turbocharger. Gases from the exhaust manifold enter the turbine casing through four inlets. The high-temperature and high-velocity exhaust gases strike the turbine disk and cause it to rotate at high speed. The turbine disk rotates in the same direction for both directions of engine rotation. The speed of the turbine is automatically controlled by the speed and load



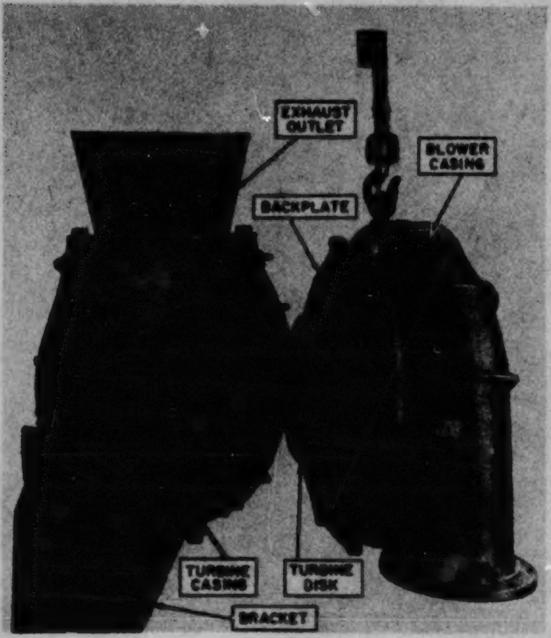
75.162

Figure 6-12.—Alco-Buchi turbocharger.

of the engine. When the gases have turned the turbine, they are discharged through the exhaust outlet.

AIR-INTAKE SYSTEM.—The air-intake system consists of a centrifugal blower mounted in a casing and an air silencer and screen. Since they are mounted on the same shaft, the blower and the turbine both rotate at the same speed. This means that both the turbine speed and the amount of fresh air discharged to the intake manifold are automatically controlled by the engine speed. The combustion air, discharged from the turbocharger, is often cooled by an aftercooler to reduce its volume prior to delivery to the combustion spaces. This air cools the parts of the cylinders and allows for higher supercharge rates.

COOLING WATER SYSTEM.—The cooling water system is connected to the freshwater cooling system of the engine. Water circulates through jackets around the turbine casing, the oil sump, and the backplate. The water cools the turbine casing, which is in constant contact with the hot exhaust gases. It also cools the lubricating oil, and the backplate prevents heat conduction to the fresh-air side of the



75.163

Figure 6-13.—Blower casing assembly removed from turbine casing (Elliott-Buchi).

turbocharger. The temperature of the intake air must be kept down since this air aids in cooling the cylinder and the exhaust valves during scavenging. Aftercoolers use saltwater as a cooling medium to achieve below-ambient temperatures.

LUBRICATING SYSTEM.—The lubricating system may, or may not, be completely separate from the engine lubricating system. In a separate system, an oil pump is driven, through reduction gears, by the shaft of the turbocharger. The pump draws oil from the sump tank and discharges it, through a filter, into the bearing support of the rotating assembly. The pump supplies oil at the proper pressure to all moving parts of the turbocharger. Oil pressure varies with turbocharger speed.

The General Electric turbocharger (fig. 6-15) operates on the same basic principle as the turbocharger just described; however, the GE turbocharger differs from the Elliot-Buchi turbocharger in certain features of design and construction. For example, the GE air filter and cleaner assembly is not an integral part of the blower. The viscous-type assembly shown in figure 6-6 is used in the intake systems of some diesel engines equipped with the GE turbochargers. Even though the GE and Elliot-Buchi turbochargers differ, the following discussion reveals a number of ways in which the two are similar.

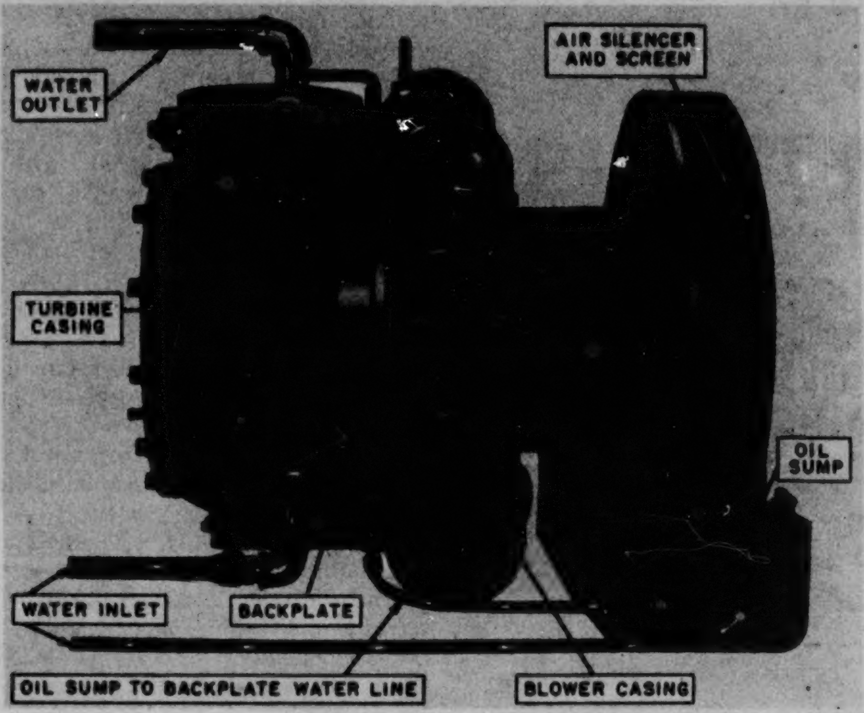
In brief, the GE turbocharger consists of an exhaust gas-driven turbine and a centrifugal compressor. The compressor impeller and the turbine wheel are mounted on a common shaft, thus forming a single unit. The compressor consists of an impeller, diffuser, and a casing. All of these parts are usually made of cast aluminum. In later models, the impeller is sometimes a forging. A water-cooled cast aluminum housing, which contains the two journal bearings and the thrust bearing, also serves as the turbine exhaust casing. The turbine assembly includes the water-cooled nozzle box, the nozzle ring or diaphragm assembly, and the turbine wheel. All of these turbine parts are made of corrosion-resistant, high-temperature alloys.

Oil for turbocharger lubrication is taken from the engine lubricating system.

Even though brief and general in some instances, the preceding account of blowers should be sufficient to clarify the principles of blower operation and some of the differences and similarities in blower construction. The details on a blower, or any engine component for that matter, should be obtained from the appropriate manufacturer's technical manual.

Intake Air Passages

Air must pass through a number of passages to reach the combustion spaces within an engine. So far, this discussion has considered the passage of air through components which clean, silence, and compress the intake air. From the blower, however, the air is discharged into a unit or passage which conducts it to the intake valves or ports of the cylinders. The design of such a unit as well as the terminology used to identify it differs, depending on the type of engine.



75.164

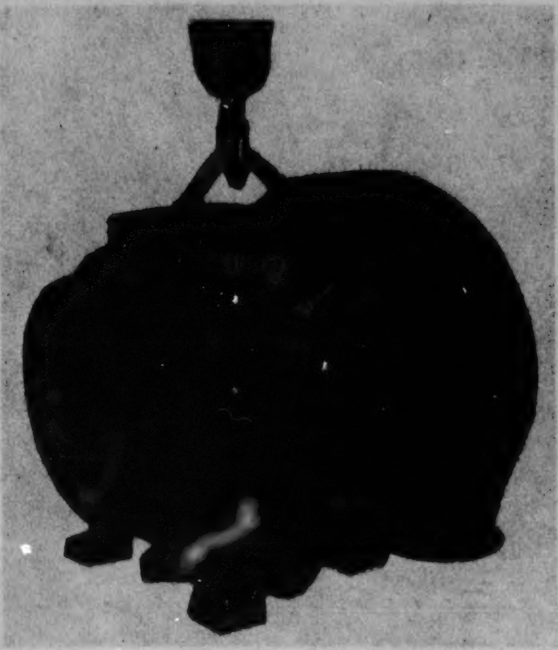
Figure 6-14.—Cooling water system of the turbocharger (General Electric).

In 2-stroke cycle engines, the passage which conducts intake air to the cylinders is generally called an AIR BOX. The air box surrounds the cylinders (fig. 6-1) and, in many engines, is built into the block. In 2-stroke cycle, V-type, diesel engines, the air box consists of the space (within the block) between the two banks of the V-construction and the open space between the upper and lower deckplates of each bank. The scavenging air passages in a Fairbanks-Morse opposed-piston engine is referred to as the AIR RECEIVER. This compartment is at the upper part of the block and surrounds cylinder liners. In some 2-stroke cycle engines, the passage which serves as a reservoir for intake air from the blower is called an AIR HEADER.

Drains are generally provided in air boxes, receivers, and headers to drain off any liquids that may accumulate. A slight amount of vapor from the air charge may condense and settle in the air box, or a small amount of lubricating oil may be blown into the air box as the piston passes the ports on the downstroke following the power event.

On some engines, the drains are vented to the atmosphere. In others, a special drain tank collects the drainage from the air box. Figure 6-16 shows the air drain tank assembly for GM series 71 engines. The purpose of the tank is to prevent drainage of oil to the engineroom. A small connection from the fuel pump also carries to the drain tank any fuel oil that may leak past the seals in the pump.

Drains are of prime importance when the air cooler is installed between the blower, or turbocharger, discharge and air intake manifold or receiver. The drains are usually left open during engine operation to prevent condensation



75.165
Figure 6-15.—General Electric turbocharger.

or water from leaky coolers being carried into the engine cylinders with the combustion air.

In 4-stroke cycle diesel engines, the intake air passage from the blower to the cylinders differs, in general, from those in 2-stroke cycle engines in that the passage is not an integral part of the block. Instead, a separate unit is attached to the block to conduct intake air to the engine cylinders. The attached unit is generally called an air intake MANIFOLD. Figure 6-17 shows both the intake and the exhaust manifolds. Note the arrows which indicate the flow of air from the turbocharger, through the intake manifold, to the cylinders and the flow of the gases from the cylinders back to the turbocharger and the exhaust.

The intake manifold shown in figure 6-17 is a one-piece fabricated steel unit. The unit is heavily insulated with felt lagging and covered with heavy canvas. The insulation dampens the noise created by the turbocharger.

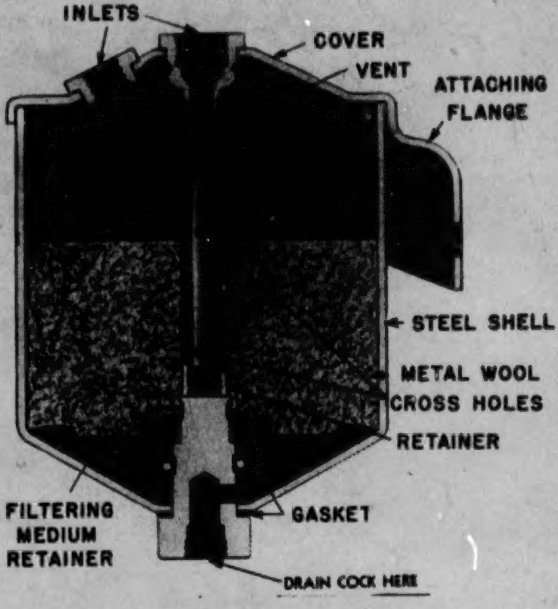


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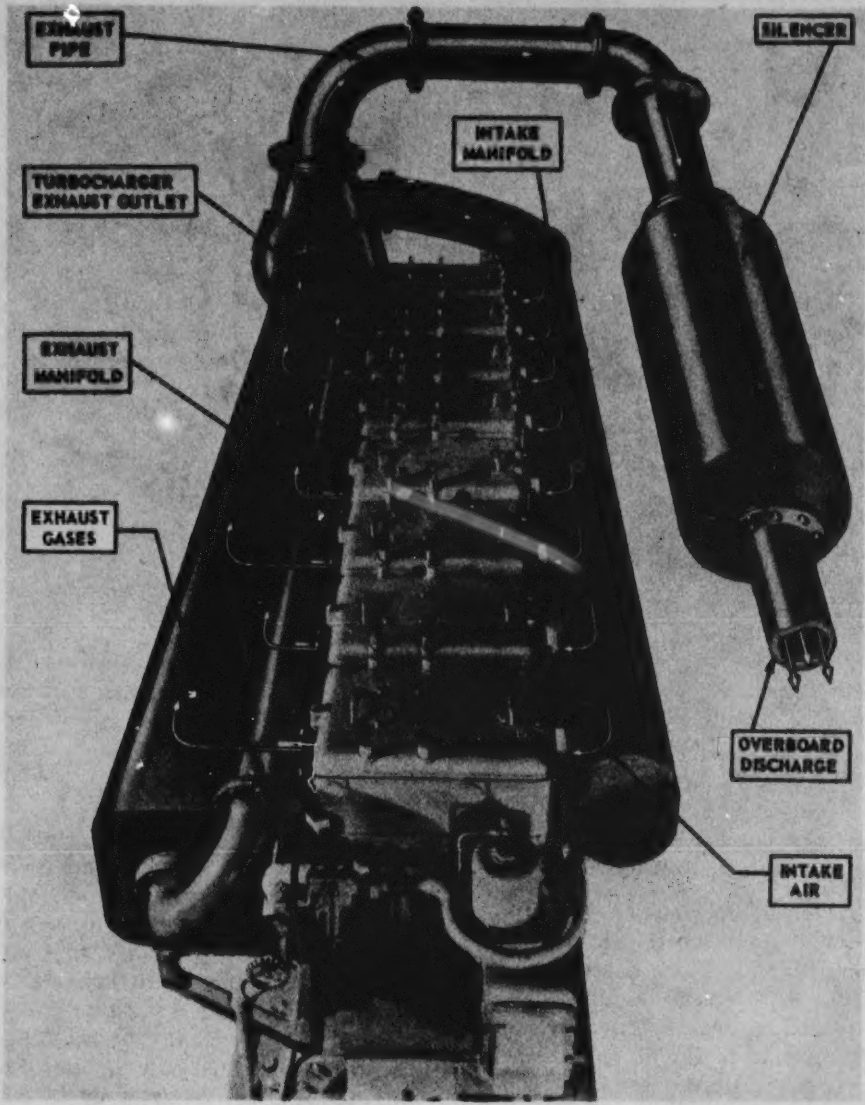
Figure 6-16.—Air box drain tank assembly (GM 71).

Cylinder Ports and Valves

The amount of air that enters the cylinders from the air box or manifold is controlled by opening and closing the cylinder valves or ports. Whether air is admitted to the cylinders of modern engines through ports or by valves depends upon the type of engine. As we stated earlier, in modern 4-stroke cycle engines, the amount of air that enters the cylinders is controlled by valves, while ports are used for this purpose in 2-stroke cycle engines. Ports control the discharge of exhaust-gases from some 2-stroke cycle engines; and valves perform the same function in all 4-stroke and in many 2-stroke cycle engines.

We have made frequent reference in this course to ports and have illustrated their location in the cylinder liner. (See fig. 6-1 and 6-2.) INTAKE PORTS are usually located in such a way that air enters the cylinder in a whirling motion. The turbulence created helps to increase the amount of intake air that is reached by the injected fuel particles; thus the


EXHAUST PIPE
SILENCER
INTAKE MANIFOLD
TURBOCHARGER EXHAUST OUTLET
EXHAUST MANIFOLD
EXHAUST GASES
OVERBOARD DISCHARGE
INTAKE AIR

75.167

Figure 6-17.—Manifolds.

power output of the engine is increased. Intake ports as well as EXHAUST PORTS are opened and closed by the piston as it moves back and forth in the cylinder. The valves of an engine are opened and closed at the proper point in the cycle of operation by a series of parts called the valve actuating mechanism or gear.

Cylinder Test Valves and Safety or Relief Valves

In some large engines, each cylinder is equipped with valves which serve different purposes from those of the intake and exhaust valves. Instead of admitting air to the cylinder or permitting the exhaust gases to escape, these valves may be used for testing or safety purposes. Even though they are not a part of the engine's air system, these valves are definitely related to this system since they are provided to test or relieve pressure which may develop with the combustion space.

A TEST VALVE is used (1) to vent the cylinder of any accumulated water or oil before an engine is started; (2) to relieve cylinder pressure when the engine is being turned by hand; or (3) to test compression and firing pressures. Test valves are hand-operated. (See fig. 6-18.)

The terms "safety valves" and "relief valves" are used by manufacturers to identify valves installed in cylinder heads or liners and designed to relieve excessive pressure that may develop when the engine is operating. Whether they are called safety valves or relief valves, these valves are designed to open when the cylinder pressure exceeds a safe operating limit.

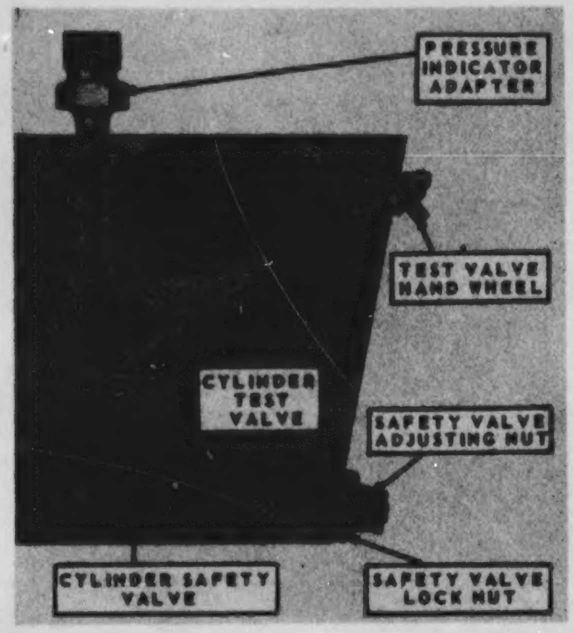


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Figure 6-18.–Cylinder test and safety valves.

A sectional view of the safety valve and test valve arrangement in the head of a GM 268A engine is shown in figure 6-18. Note the passage and adapter for a cylinder pressure indicator. Most test and relief valve arrangements have an adapter for the cylinder pressure measuring instrument.

The valves shown in figure 6-18 are fitted in passages within the cylinder head. In some engines, however, the relief valve is attached separately to the exterior of the head or liner. For example, the cylinder relief valve of an FM 38D8 1/8 is screwed into an adapter which also has a tapped opening for an indicator valve. The adapter is attached to the cylinder liner adapter sleeve.

Many cylinder safety or relief valves are of the spring-loaded, poppet type. There are devices for adjusting the valves to open when a predetermined pressure is reached in the cylinder.

EXHAUST SYSTEMS

The parts of engine air systems considered so far have provided a passage for air into the cylinders and for the release of gases from the cylinders after combustion. The relationship of blowers, or turbochargers, to both the intake and exhaust systems has also been pointed out.

The system which functions primarily to carry gases away from the cylinders of an engine is called the exhaust system. In addition to this principal function, an exhaust system may be designed to perform one or more of the following functions: muffle exhaust noise, quench sparks, remove solid material from exhaust gases, and furnish energy to a turbine-driven supercharger. In the following sections, we will discuss the principal parts that may be used in combination to accomplish the functions of an engine exhaust system.

EXHAUST MANIFOLDS

When the gases of combustion are forced from the cylinders of an engine, the gases enter a unit which is generally referred to as the manifold. The unit that receives the gases of combustion is sometimes called a header or belt.

The interior of the exhaust manifold shown in figure 6-17 is illustrated in figure 6-19.

The exhaust manifold is flanged to the exhaust valve ports (fig. 6-17) of the engine with gaskets between the flanges and the cylinder heads. The cylinders are connected in pairs to four lines within the manifold. Each of the lines has a joint which allows for the expansion caused by the heat. A water jacket surrounds the bank of exhaust tubes to reduce heat radiation into the engineroom. (The exhaust manifolds of most marine engines are water cooled.) A protective resin compound is baked onto the water jacket to prevent corrosion.

The manifold shown in figure 6-19 is a one-piece unit, fabricated of steel. Some manifolds are made of steel plate with welded joints and branch elbows of steel castings, while others are made of aluminum castings. On some engines, all exposed surfaces of exhaust manifolds and related parts are insulated with layers of spun glass held in place by laced-on woven asbestos covers. The insulation helps to reduce heat radiation. Usually, there are expansion joints between the manifold sections and the turbochargers or other outlet connections.

The exhaust manifold shown in figure 6-19 is the passage for gases from the combustion spaces to the exhaust inlet of the turbocharger. Thus, the turbine end of the turbocharger may be considered as part of the exhaust system since it forms part of the passageway for the escape of gases to the exhaust outlet. (See fig. 6-13 and 6-17.) A similar arrangement is characteristic of other 4-stroke cycle, supercharged diesel engines.

PYROMETERS

On some diesel engines the exhaust system has a device for measuring the exhaust temperature. The device most commonly used is a pyrometer. By comparing the exhaust gas temperature of each cylinder, the operator can determine if the load is balanced throughout the engine.

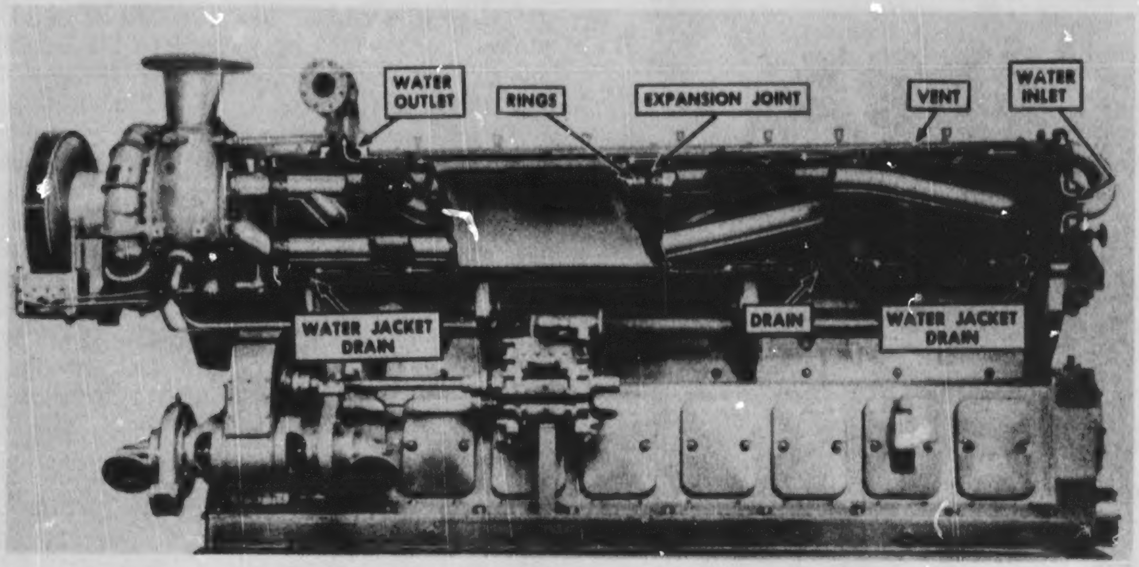

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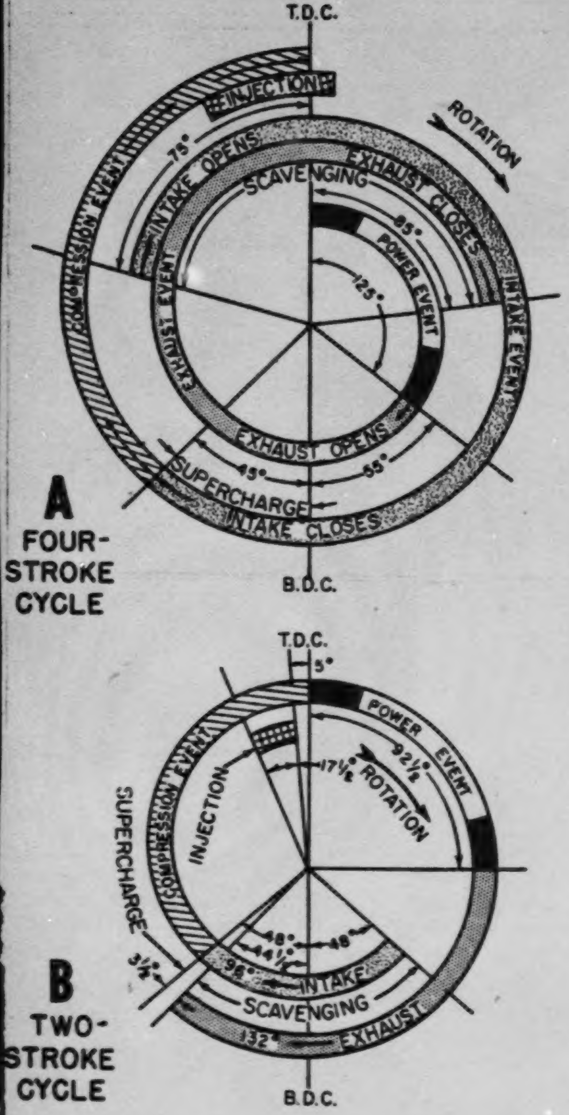
Figure 6-19.—Water-jacketed exhaust manifold.


T.D.C.
INJECTION
ROTATION
75°
INTAKE OPENS
EXHAUST CLOSES
SCAVENGING
85°
POWER EVENT
125°
COMPRESSION EVENT
INTAKE EVENT
EXHAUST EVENT
INTAKE EVENT
EXHAUST OPENS
45°
55°
SUPERCHARGE
INTAKE CLOSES
B.D.C.
A
FOUR-STROKE CYCLE
T.D.C.
5°
POWER EVENT
92½°
17½°
ROTATION
COMPRESSION EVENT
INJECTION
SUPERCHARGE
48°
48°
44½°
3½°
96°
INTAKE
SCAVENGING
132°
EXHAUST
B.D.C.
B
TWO-STROKE CYCLE

2.24

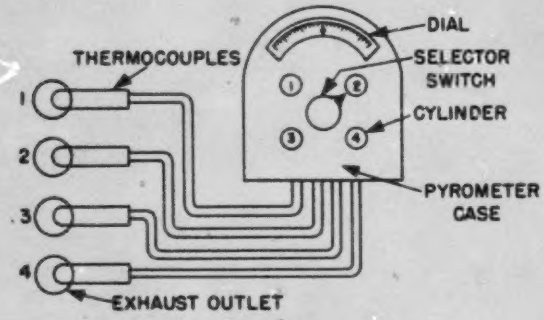
Figure 6-3.—Scavenging and supercharging in diesel engines.

The indicating unit of the pyrometer is calibrated to give a direct reading of temperature. However, the pyrometer actually measures the difference between the electric current produced by heat acting on dissimilar metals in the thermocouple hot junction and cold junction.

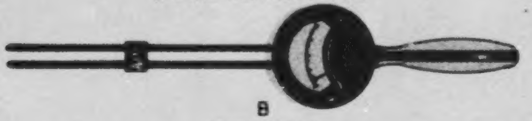
The metals most commonly used in the thermocouple are iron and constantin which are covered by an insulator. The thermocouple is placed so that the hot junction is in contact with the exhaust gases.

Since the pyrometer measures the difference between the hot junction and the cold junction, the temperature at the cold junction must either be constant or compensated for, if the temperature reading on the indicating unit is to have any meaning.

There are two types of pyrometers used to take exhaust temperature readings, the fixed installation and the portable hand-recording instrument (fig. 6-20). Both types use a thermocouple unit, such as shown in figure 6-21, installed in the exhaust manifold.



A
(FIXED INSTALLATION)



B
(PORTABLE)

75.170
Figure 6-20.—Pyrometers used in diesel engine exhaust systems.

75.171
Figure 6-21.—Sectional view of a thermocouple.

Pyrometers of the fixed installation type (fig. 6-20A) have a thermostatically operated control spring which makes the required temperature corrections automatically. The portable hand pyrometer (fig. 6-20B) has a zero adjuster which must be set by hand.

EXHAUST PIPING AND SILENCERS (MUFFLERS)

After passing through the turbine end of the turbocharger of a 4-stroke cycle engine or after being discharged from the exhaust manifold [illegible] a natural aspirated 4-stroke cycle engine or after being discharged from the exhaust manifold of a 2-stroke cycle engine, the gases pass through the exhaust pipe (flexible or rigid) to the silencer, or muffler. The gases are discharged from the silencer to the atmosphere through the tail pipe or overboard discharge pipe. (See fig 6-1 and 6-17.)

Silencers, or mufflers, are placed on internal-combustion engines mainly to reduce the noise created by the exhaust as the exhaust valves or ports open. The noise of the exhaust can be reduced by placing sound-absorbent, flame-proof material in the exhaust passages, but the resulting back pressure might keep the engine from operating. Because of the serious effects of back pressure upon the operation of the engine, the device used to reduce the noise of the exhaust must be designed to keep the exhaust back pressure to a minimum.

Most modern marine engines use a wet type exhaust silencer. (See fig. 6-1 and 6-17.) Wet type mufflers are usually made of cast or sheet iron with a system of internal baffles to break up the exhaust gas pulsation. This construction gives a silencing effect without producing a back pressure. The water used in wet type silencers also helps to reduce noise. The water cools the exhaust gases, causing the gases to contract. The decrease in volume reduces the velocity of the exhaust gases and thereby reduces the exhaust noise. The water itself absorbs some of the sound.

The silencer shown in figure 6-1 consists of a steel drum divided into two compartments by a transverse baffle plate. The exhaust inlet pipe extends in such a way that the exhaust gases must circle back and pass through a stream of water before they enter the pipes which extend through the baffle plate.

In the outlet compartment, the exhaust gases are again deflected before they enter the water outlet pipe. A second stream of water enters the tail pipe and helps carry the gases to the overboard discharge.

Some marine engines use a dry type exhaust silencer. In both the wet and dry type silencers of most marine installations, circulating water is used to reduce the temperature of the exhaust gases. The principal difference between the two is that in the dry type the exhaust gases do not come in contact with the cooling water; in other words, the water does not flow through the silencer compartment but flows, instead, through a jacket around the silencer. In wet type silencers the gases are expanded into the silencer and come in direct contact with the water. In passing through the baffles and through the water, the gases are cooled, condensed, decreased in volume, and effectively silenced.

In addition to acting as silencers, most mufflers also act as spark arresters. The water in wet type silencers is a spark arrester. Some dry type silencers have a device that traps burning carbon particles and soot.

The interiors of all mufflers are subjected to moisture: condensation in dry type mufflers and the supplied water in wet type mufflers. Because of this, most silencers are coated inside and out with a corrosion-resistant material.

PARTS OF OTHER SYSTEMS RELATED TO ENGINE AIR SYSTEMS

The parts discussed in this chapter are those generally associated with the air systems of most engines. Some engines are equipped with parts which perform special functions. These parts, even though related to the engine air systems, are more frequently considered as parts of other engine systems.

For example, some engines are equipped with intake air heaters or use other methods to overcome the influence of low temperatures in cold weather starting. Devices and methods used for this purpose are discussed in later chapters.

Some engines are equipped with devices to cool the compressed air that is discharged from the supercharger. Devices used for cooling the air are discussed with the engine cooling systems.

Many engines are equipped with devices or systems which provide crankcase ventilation. Blower action is necessary in many ventilation systems. The systems operate to prevent contamination of engineroom spaces with heated or fume-laden air, to reduce the formation of sludge in lubricating oil, and to prevent the accumulation of combustible gases in the crankcase and in the oil pan or sump. Devices used to ventilate engine crankcases are discussed with the lubricating systems.

CHAPTER 7

ENGINE STARTING SYSTEMS

The operating principles of the starting systems used with internal-combustion engines and the ignition systems common to gasoline engines are described in this chapter.

STARTING SYSTEMS

As an Engineman you will be concerned with the three types of starting systems used with internal-combustion engines—electric, hydraulic, and air. Electric starting systems are used with gasoline engines and some high-speed diesel engines. The air starting system is used wherever practicable for starting diesel engines because it contains sturdier components and requires less maintenance. The hydraulic starting system is used where nonmagnetic or lightweight characteristics are required.

ELECTRIC STARTING SYSTEMS

Electric starting systems use direct current because electrical energy in this form can be stored in batteries and drawn upon when needed. The battery's electrical energy can be restored by charging the battery with an engine-driven generator.

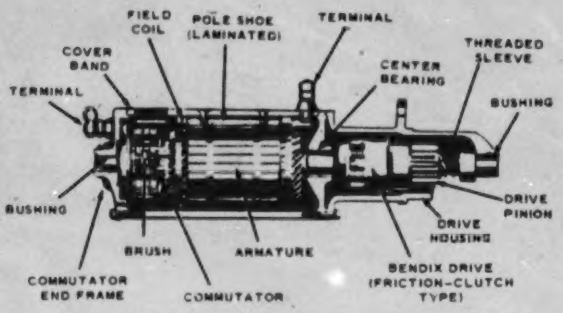
The main components of the electric starting system are a storage battery, starting motor, generator, and associated control and protective devices. The storage battery is described in detail in *Basic Electricity*, NAVPERS 10086-B, and in *Fireman*, NAVEDTRA 10520-E, and therefore is covered only lightly in this manual.

Starting Motors and Drives

The starting motor for diesel and gasoline engines operates on the same principle as a direct current electric motor. The motor is designed to carry extremely heavy loads but tends to overheat quickly because it draws a high current (300-665 amperes). To avoid overheating, NEVER allow the motor to run for more than 30 seconds at a time. Then allow it to cool for 2 or 3 minutes before using it again.

To start a diesel engine, you must turn it over rapidly to obtain sufficient heat to ignite the fuel. The starting motor is located near the flywheel. The drive gear on the starter is arranged so that it can mesh with the teeth on the flywheel when the starting switch is closed. The drive mechanism has three functions: (1) to transmit the turning power to the engine when the starting motor runs, (2) to disconnect the starting motor from the engine immediately after the engine has started, and (3) to provide a gear reduction ratio between the starting motor and the engine. (The gear ratio between the driven pinion and the flywheel is usually about 15 to 1. This means that the starting motor shaft rotates 15 times as fast as the engine. or at 1500 rpm to turn the engine at a speed of 100 rpm.)

The drive mechanism must disengage the pinion from the flywheel immediately after the engine starts. After the engine starts, the engine speed may increase rapidly to approximately 1500 rpm. If the drive pinion remained meshed with the flywheel and also locked with the shaft of the starting motor at a normal engine speed (1500 rpm), the shaft would be spun at a rapid rate—22,500 to 30,000 rpm. At such speeds, the starting motor would be badly damaged.


FIELD COIL
POLE SHOE (LAMINATED)
TERMINAL
COVER BAND
THREADED SLEEVE
CENTER BEARING
TERMINAL
BUSHING
BUSHING
DRIVE PINION
DRIVE HOUSING
BRUSH
ARMATURE
BENDIX DRIVE (FRICTION-CLUTCH TYPE)
COMMUTATOR END FRAME
COMMUTATOR

75.172

Figure 7-1.—A starting motor with Bendix drive.

BENDIX DRIVE MECHANISMS.—The Bendix drive is an example of a starting motor drive mechanism used on Navy diesel engines, such as the General Motors Model 268A. The drive mechanism moves the drive pinion so that it meshes with the ring gear on the flywheel. Figure 7-1 illustrates a starting motor equipped with a Bendix drive friction-clutch type mechanism.

The pinion of the Bendix drive is mounted on a spiral-threaded sleeve so that when the shaft of the motor turns, the threaded sleeve rotates within the pinion, moving the pinion outward, causing it to mesh with the flywheel ring gear and crank the engine. A friction clutch absorbs the sudden shock when the gear meshes with the flywheel.

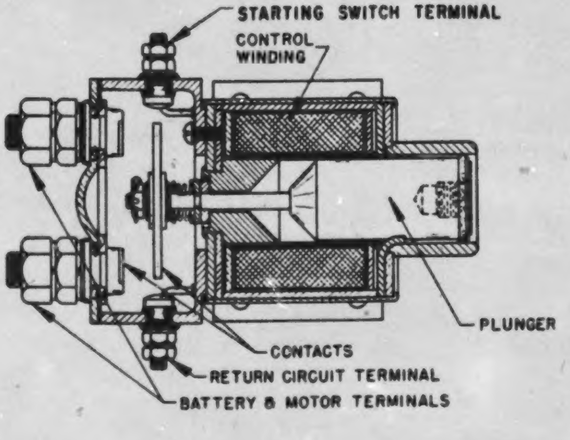
As soon as the engine runs under its own power, the flywheel drives the Bendix gear at a higher speed than the shaft of the starting motor is rotating. This causes the pinion to rotate in the opposite direction on the shaft spiral and automatically disengages the pinion from the flywheel as soon as the engine starts.

Special switches are needed to carry the heavy current drawn by starting motors. Starting motors that have a Bendix drive use a heavy duty solenoid switch (relay switch) to open and close the motor-to-battery circuit and a hand-operated starting switch to operate the solenoid switch. The starting switch is on the instrument panel and may be a pushbutton or a lever type. The solenoid switch (fig. 7-2) is mounted on and grounded to the starting motor housing so that the heavy current wires may be as short as possible. When the solenoid is energized by the starting switch, the plunger is drawn into the core and completes the circuit between the battery and the starting motor.

OPERATING PRECAUTIONS on the Bendix drive must be strictly followed. There are times when the engine starts, throws the piston out of mesh, and then stops. When the engine is coming to rest, it often rocks back part of a revolution. If at that moment an attempt is made to engage the pinion, the drive mechanism may be seriously damaged. Therefore, you must wait several seconds to be sure that the engine is completely stopped before you use the starting switch again.

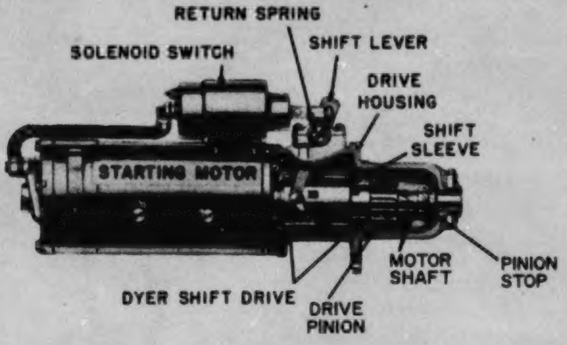
At times the pinion will fail to immediately engage after the starting motor has been energized. When this happens, you will fail to hear the engine turning over and the starting motor will develop a high-pitched whine. You should immediately de-energize the starting motor to prevent overspeeding. An electric starting motor operating under no-load conditions can quickly overspeed and cause serious damage.

If the pinion is to engage and disengage freely, the sleeve and the pinion threads should


STARTING SWITCH TERMINAL
CONTROL WINDING
PLUNGER
CONTACTS
RETURN CIRCUIT TERMINAL
BATTERY & MOTOR TERMINALS

75.173

Figure 7-2.—Solenoid switch.



75.174

Figure 7-3.–A starting motor with Dyer shift drive.

be free from grease and dirt. The Bendix drive should be lubricated in accordance with instructions in the manufacturer's technical manual.

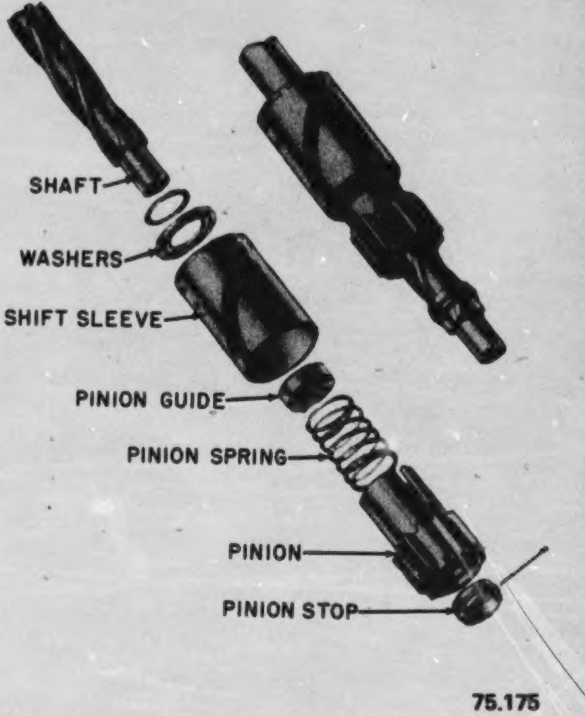
DYER DRIVE MECHANISMS.–A starting motor assembly with the Dyer drive mechanism is illustrated in figure 7-3. In this system, the drive pinion meshes with the flywheel ring gear BEFORE the starting motor switch is closed and before the motor shaft begins to rotate. This prevents the pinion teeth from clashing with the flywheel ring gear and also the possibility of broken or burred teeth on either the ring gear or the drive pinion.

Figure 7-4 shows two views of the Dyer shift drive–a separate drive assembly and a disassembled mechanism. The upper end of the shift lever is linked to the solenoid switch, mounted on top of the starter. The shift lever moves the entire drive mechanism axially along the motor shaft toward the flywheel. At the end of this movement, the drive pinion is meshed with the flywheel ring gear and has come to rest against the pinion (fig. 7-3).

When the shaft of the starting motor begins to rotate, the shift sleeve returns to its original position, out of the way. The instant the engine starts, the ring gear tries to spin the pinion faster than the motor shaft is turning. This causes the pinion and pinion guide to spin back out of mesh, and the pinion guide (fig. 7-4) automatically locks the pinion in the disengaged position.

Operation of the solenoid switch is similar to that of the switch used with the Bendix drive. When the starting switch is operated, the solenoid closes the starting motor switch and moves the shift lever to engage the drive pinion with the flywheel ring gear. Closing the starting motor switch energizes the starting motor, which cranks the engine. When the engine starts, the pinion and the pinion guide spin out of mesh with the ring gear and lock in the disengaged position. The starting motor continues to rotate as long as the starting switch is operated. However, the pinion cannot engage the ring gear until the starting motor is stopped and the shift lever is allowed to return to its original position.

Four stages of operation of the Dyer shift drive are shown in figure 7-5: In A, the mechanism is in the disengaged position. In B, the starting switch has been operated and the



75.175

Figure 7-4.–Dyer shift drive mechanism.

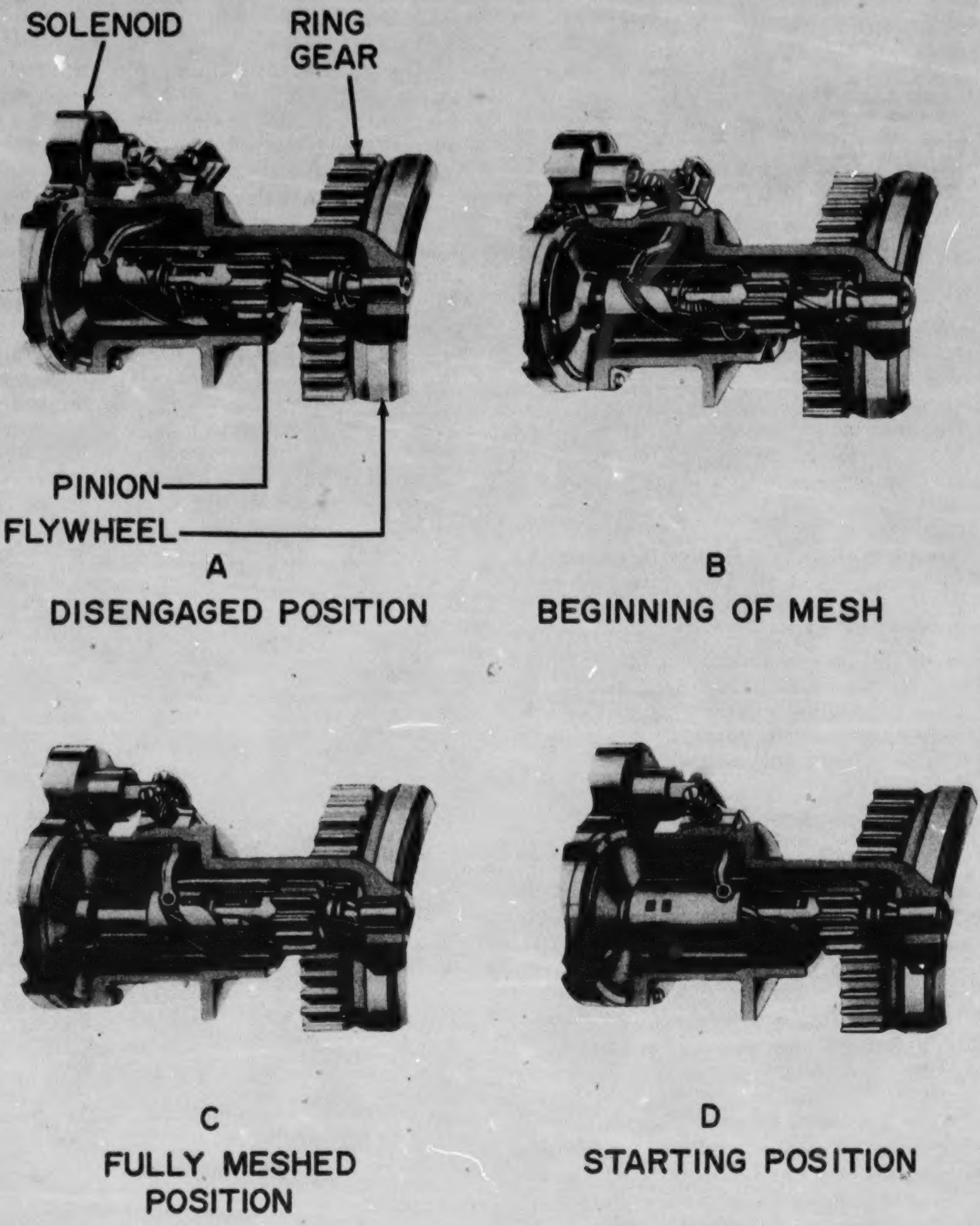

SOLENOID
RING GEAR
PINION
FLYWHEEL
A
DISENGAGED POSITION
B
BEGINNING OF MESH
C
FULLY MESHED POSITION
D
STARTING POSITION
75.176

Figure 7-5.—Dyer drive operation.

solenoid is pulling its plunger in and beginning to move the pinion toward the ring gear. In C, the pinion has fully meshed with the ring gear, but the motor shaft has not turned far enough to return the shift sleeve. In D, the motor shaft has returned the shift sleeve to its original position and is starting the engine.

SPRAG OVERRUNNING CLUTCH DRIVE.–Another type of drive mechanism used by the Navy is the Sprag overrunning clutch. This type drive is similar to the Dyer drive in that the pinion is engaged by the action of a lever attached to the solenoid plunger. Once engaged, the pinion will stay in mesh with the flywheel ring gear until the engine is started or the solenoid switch is disengaged. To protect the starter armature from excessive speeds when the engine starts, the clutch "overruns" or turns faster than the armature, which permits the starter pinion to disengage itself from the flywheel ring gear.

The solenoid plunger and shift lever, unlike the Dyer drive, are completely enclosed in a housing to protect them from water, dirt, and other foreign matter. An oil seal, installed between the shaft and lever housing and a linkage seal around the solenoid plunger prevent transmission oil from entering the starter frame or solenoid case. The nose housing of the drive mechanism can be rotated to obtain a number of solenoid positions with respect to the mounting flange.

Generators and Controls

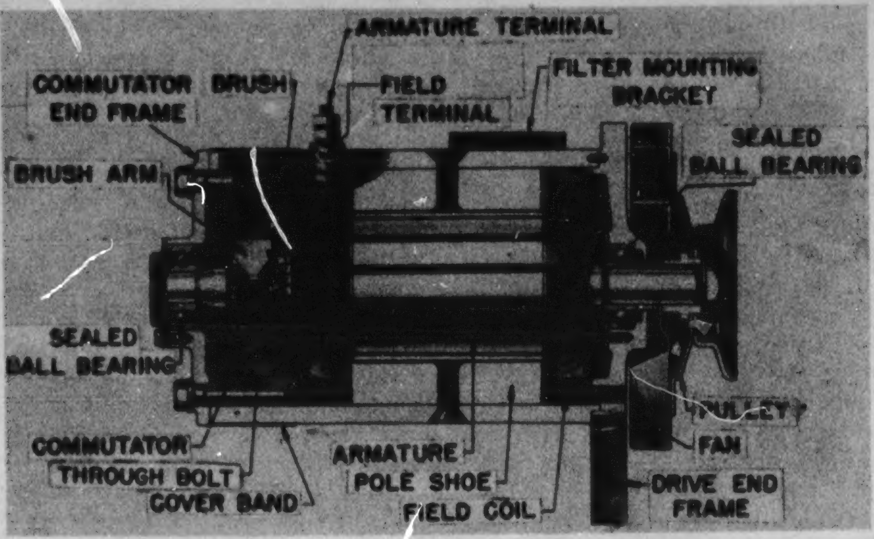
A generator provides the electrical current to maintain the storage battery in a charged condition. The design of a battery-charging generator depends on many factors: maximum electrical load, design of the charging circuit, type of service, ratio of engine idling time to running time, type of drive, and drive ratio (engine rpm to generator rpm).

To maintain the battery in a fully charged condition, the discharge current must be balanced by a charging current from an external source, such as a battery-charging generator. If the discharge current is greater than the charging current for an appreciable period, the battery will gradually lose its charge and will not be able to supply the necessary current to the electrical system.

Battery-charging generators sometimes are flange-mounted on the rear of the engine and driven from the timing gear train, but usually they are cradle-mounted on the side of the engine and driven by a V-belt from the crankshaft pulley. These generators are rated according to the particular application and are designed for clockwise or counterclockwise rotation. They are supplied for use with either 6- or 24-volt systems. Battery-charging generators used with the electrical systems in small craft are usually d.c. generators similar to the one shown in figure 7-6. An a.c. generator (alternator) is installed on some engines because it produces a constant output over a speed range that varies from idle to top engine speed. A voltage regulator controls the output voltage of the alternator and prevents overcharging the battery. An a.c. generator is equipped with a rectifier which functions to convert a.c. current to d.c. current. A current-limiting device associated with the regulator is provided which protects the alternator and rectifier. An alternator-equipped, battery-charging system is shown in figure 7-7.

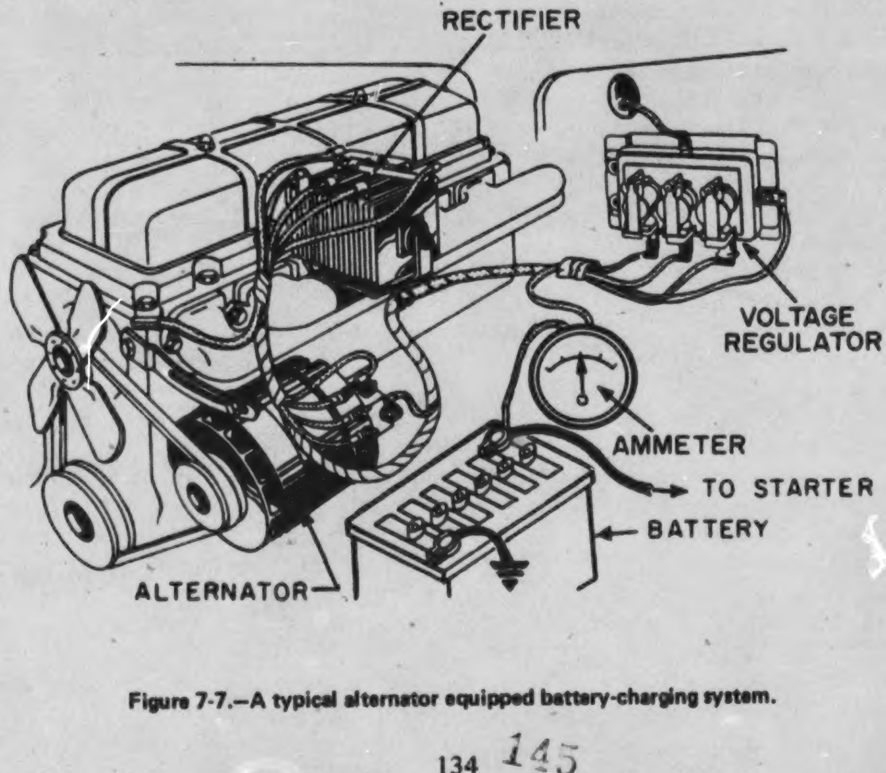
A d.c. battery-charging generator system also uses a control to regulate the output of the generator. The type of control used is determined by the design of the generator. Although such controls may control both current and voltage, they are commonly called voltage regulators. Voltage regulators differ considerably in design, but they all serve essentially the same functions. When a d.c. generator is operating and the electrical load is heavy, the output of the generator is connected through the voltage regulator to the battery; but when the electrical load is light or when there is no load and the battery is fully charged, the voltage regulator operates to prevent the output of the generator from reaching the battery.

The voltage regulator also protects the components of the battery-charging system. It


ARMATURE TERMINAL
COMMUTATOR BRUSH END FRAME
FIELD TERMINAL
FILTER MOUNTING BRACKET
SEALED BALL BEARING
BRUSH ARM
SEALED BALL BEARING
PULLEY
FAN
COMMUTATOR
THROUGH BOLT
COVER BAND
ARMATURE
POLE SHOE
FIELD COIL
DRIVE END FRAME

75.177

Figure 7-6.—Typical d.c. generator.


RECTIFIER
VOLTAGE REGULATOR
AMMETER
TO STARTER
BATTERY
ALTERNATOR

75.178

Figure 7-7.—A typical alternator equipped battery-charging system.

protects the battery by preventing overcharging and by preventing current from flowing from the battery to the d.c. generator when the generator output voltage, which is determined by the speed of the engine, is less than the voltage of the battery. The voltage regulator protects the generator by preventing the output from exceeding the design limits of the generator.

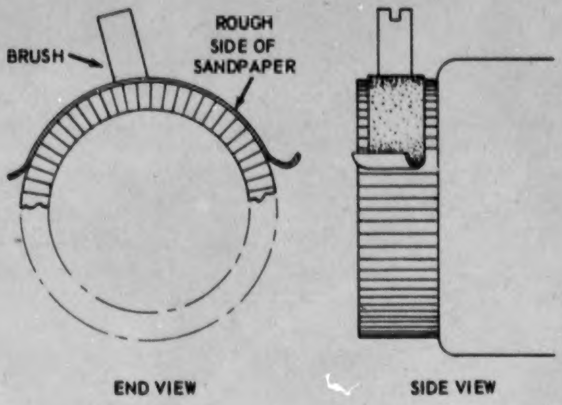
Generator Maintenance

Proper maintanance is important in ensuring long and satisfactory service of generators. The most important factor in maintenance is to keep the equipment clean and free of oil, water, dirt and other foreign particles. It is also important to keep the insulation clean. Dust and dirt tend to block the ventilation passage and increase resistance to the dissipation of heat, thus, causing local or general overheating. If the particles are conducting or form a conducting paste, the windings may be eventually grounded or short circuited.

The four methods of cleaning generators are wiping, compressed air, suction, and solvent. In using compressed air, remember it should always be clean and free of moisture.

You should avoid using solvent for cleaning electrical equipment whenever possible; however, you may find it necessary to use solvent at times to remove gummy or greasy substances. NEVER use solvents containing gasoline or benzine under any circumstances. Alcohol will injure most types of insulating varnishes. Inhibited methyl chloroform (trichloroethylene) is one of the principal approved solvents for cleaning electrical equipment, although it should be noted trichloroethylene is authorized for use aboard tenders only.

Improper lubrication procedures are a frequent cause of generator failures. Excess grease or oils can be forced through the bearing housing seals and into the commutators, eventually resulting in grounds or short circuits. The excessive quantity and pressure of the grease in the bearing housing results in churning, high temperatures, and rapid deterioration of the grease and bearings.

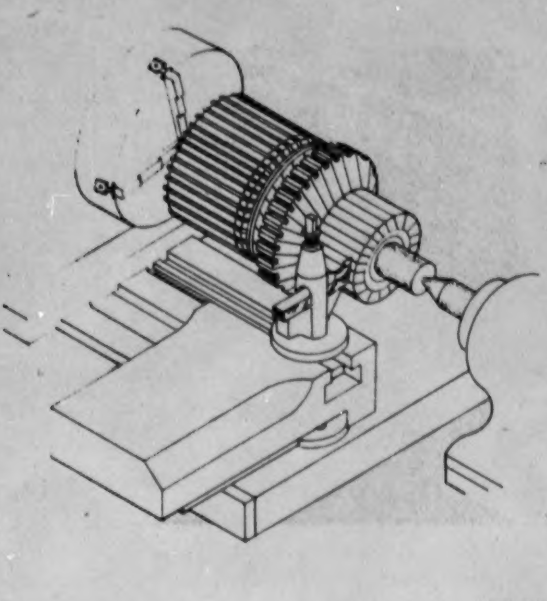


1.52

Figure 7-8.—Method of sanding brushes.

The brushes used in generators are one or more plates of carbon, bearing against a commutator, to provide a passage of electrical current to an external circuit. The brushes are held in place by brush holders mounted on studs or brackets attached to the brush mounting ring. Check the brushes frequently to be sure they are in good condition and free to move in their holder. The brushes should move smoothly without vibration. If the brushes do not slide smoothly on the commutator, the current output will become erratic. The brushes should be renewed when they are worn to half of their original length. You can seat the brushes against the commutator by accurately inserting a strip of No. 00 sandpaper, approximately the width of the commutator with the rough side up, between the commutator and the brushes as shown in figure 7-8.

With the sandpaper held firmly against the commutator and the brushes held in place by normal spring tension, pull the sandpaper in the direction of normal rotation of the commutator. When returning the sandpaper for another pull, you must lift the brushes. The brushes should be finished with a finer grade of sandpaper and all



77.74

Figure 7-9.—Truing commutator by turning.

dust particles should be removed after the sanding.

After being used for approximately 2 weeks, the commutator should develop a uniform glazed dark brown color on the places where the brushes ride. If a nonuniform or bluish color appears, improper commutation conditions are indicated. Periodic inspections and proper cleaning practices will keep the commutator's troubles to a minimum. One of the most effective ways to clean a commutator is to apply a canvas wiper while the commutator is being turned. However, small generators will have to be disassembled for a thorough job. When the generator is disassembled, you can also use a toothbrush to clean out the slots. If on inspection you note that the commutator is worn or grooved excessively, you can true it by turning it on a lathe. (See fig. 7-9.)

HYDRAULIC STARTING SYSTEMS

There are several types of hydraulic starting systems in use. In most installations, the system consists of a hydraulic starting motor, a piston type accumulator, a manually operated hudraulic pump, an engine-driven hydraulic pump, and a reservoir for the hydraulic fluid. One type of hydraulic starting system (Aeroproducts, GM), is illustrated in figure 7-10.

Hydraulic pressure is obtained in the accumulator by the manually operated hand pump or from the engine-driven pump when the engine is operating.

When the starting lever is operated, the control valve allows hydraulic oil (under pressure) from the accumulator to pass through the hydraulic starting motor, thereby cranking the engine. When the starting lever is released, spring action disengages the starting pinion and closes the control valve, stopping the flow of hydraulic oil from the accumulator. The starter is protected from the high speeds of the engine by the action of an overrunning clutch.

The hydraulic starting system is being used on some smaller diesel engines. This system can be applied to most engines now in service without modification other than the clutch and pinion assembly, which must be changed when converting from a left-hand to a right-hand rotation.

AIR STARTING SYSTEMS

Most modern large diesel engines are started by admitting compressed air into the engine cylinders at a pressure capable of turning over the engine. The process is continued until the pistons have built up sufficient compression heat to cause combustion. The pressure used in air starting systems ranges from 250 to 600 psi.

Some larger engines and several smaller engines are provided with starting motors driven by air. These motors are similar to those used to drive such equipment as large pneumatic drills and engine jacking motors. Air starting motors are usually driven by air pressures varying from 90 to 200 psi.

Follow the numbered parts in the exploded view of an air starting motor in figure 7-11 as we continue the discussion.

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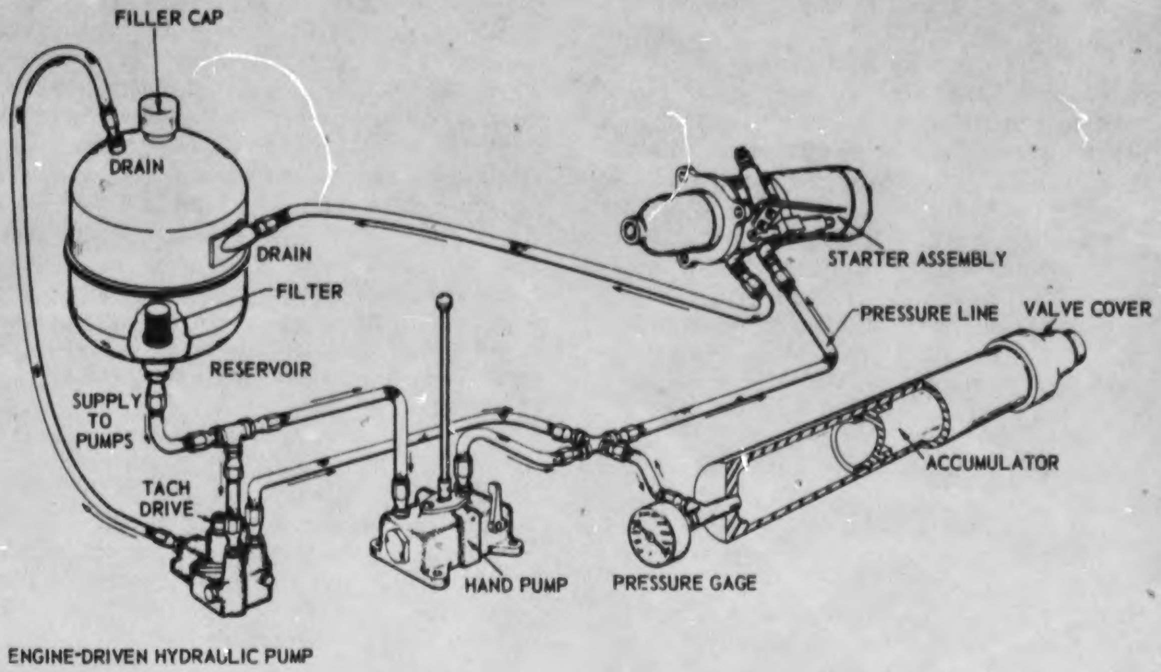
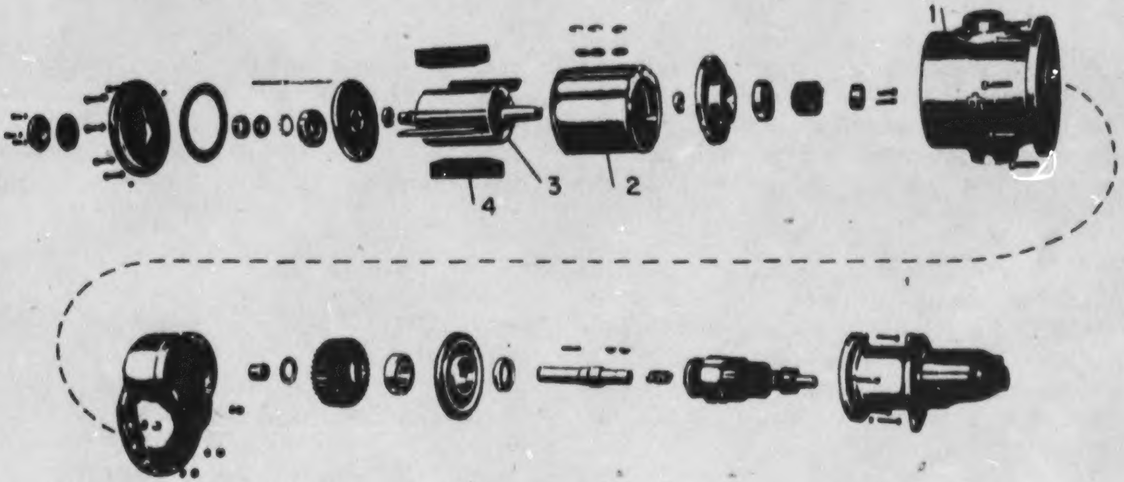

FILLER CAP
DRAIN
DRAIN
FILTER
RESERVOIR
SUPPLY TO PUMPS
TACH DRIVE
ENGINE-DRIVEN HYDRAULIC PUMP
HAND PUMP
PRESSURE GAGE
STARTER ASSEMBLY
PRESSURE LINE
VALVE COVER
ACCUMULATOR

75.179

Figure 7-10.—Hydraulic starter system.



256.150

Figure 7-11.—Air starting motor-exploded view.

148

Starting air enters through piping into the top of the housing (1), flowing into the top of the cylinder (2). The bore of the cylinder is egg-shaped Inside the cylinder is a slotted rotating member (3) in which springloaded vanes (4) ride in slots and maintain contact with the bore of the cylinder. The pressure of the starting air against the vanes forces the rotating member to turn approximately halfway around the core of the cylinder where exhaust ports allow the air to escape to the atmosphere. The rotating member is connected by a shaft and reduction gear to a Bendix drive which engages the flywheel ring gear and rotates the engine.

Source of Starting Air

Starting air comes directly from the ship's medium- or high-pressure air service line or from starting air flasks which are included in some systems for the purpose of storing starting air. From either source, the air, on its way to the engine, must pass through a pressure-reducing valve which reduces the higher pressure to the operating pressure required to start a particular engine. A relief valve is installed in the line between the reducing valve and the engine.

The relief valve is normally set to open at 12% above the required starting air pressure. If the air pressure leaving the reducing valve is too high, the relief valve will protect the engine by releasing air in excess of a pre-set value and permit air only at safe pressure to reach the cylinders.

One type of pressure-reducing valve is the regulator shown in figure 7-12, in which compressed air, sealed in a dome, furnishes the regulating pressure that actuates the valve. The compressed air in the dome performs the same function as a spring used in a more common type of regulating valve.

The dome is tightly secured to the valve body, which is separated into an upper (low-pressure outlet) and a lower (high-pressure inlet) chamber by the main valve. At the top of the valve stem is another chamber which contains a rubber diaphragm and a metal diaphragm plate. This chamber has an opening leading to the low-pressure outlet chamber. When the outlet pressure drops below the pressure in the dome, air in the dome forces the diaphragm and the diaphragm plate down on the valve stem. This partially opens the valve and permits high-pressure air to pass the valve seat into the low-pressure outlet and into the space under the diaphragm. As soon as the pressure under the diaphragm is equal to that in the dome, the diaphragm returns to its normal position, and the valve is forced shut by the high-pressure air acting on the valve head.

During the starting cycle, the regulator valve continuously and rapidly adjusts for changes in air pressure by partially opening and partially closing to maintain a safe, constant starting pressure. When the engine starts and there is no longer a demand for air, pressure builds up in a low-pressure chamber to equal the pressure in the dome, and the valve closes completely.

High-pressure air entering the valve body is filtered through a screen to prevent the entrance of any particle of dirt which would prevent the valve from seating properly. The screen is held in position around the space under the valve head by the threaded valve seat bushing. This screen should be removed and cleaned periodically to ensure an unrestricted flow of air. If particles of dirt are permitted to accumulate in the screen, the resultant buildup of high air pressure may tear the screen from its position and force it into the working parts, causing damage to the valve seat.

Air for the original charging of the dome is obtained from the high-pressure chamber of the valve body by manually opening two needle valves. As soon as the desired pressure (as indicated by the gage on the discharge side of the regulator) is reached, the needle valves must be closed. The dome will then regulate and maintain the discharge of air at that pressure.

Starting Mechanism

Basically, all air starting systems operate similarly and contain the same elements. If you

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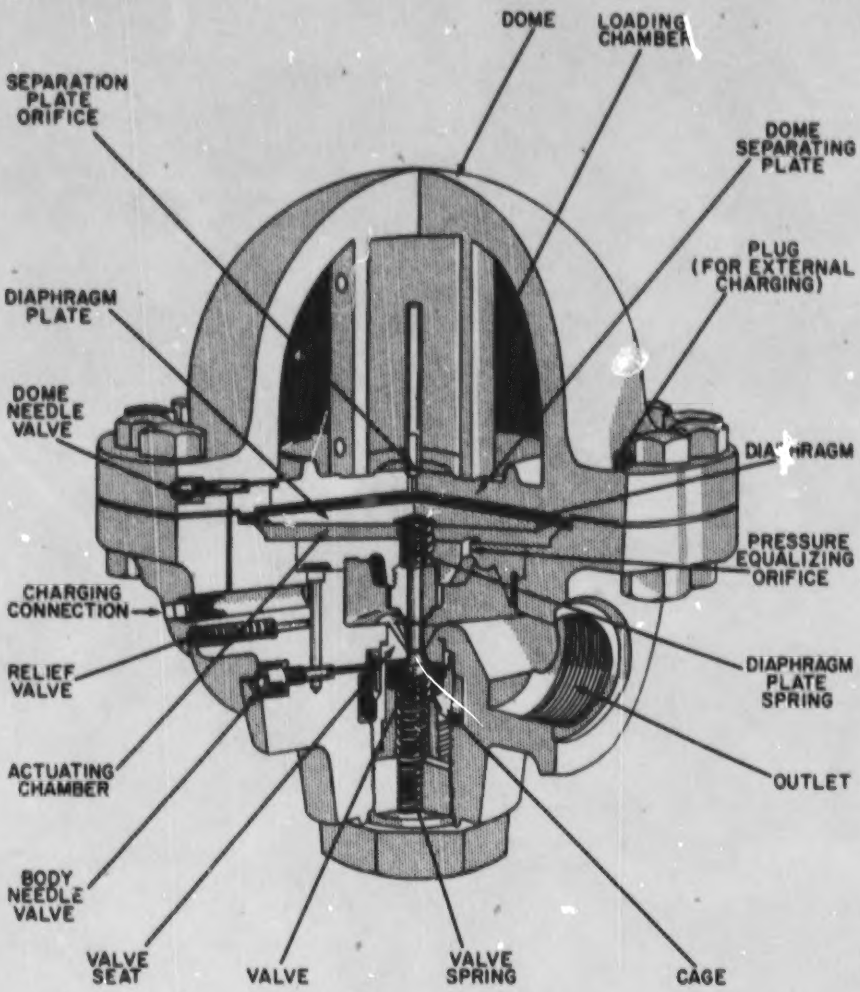

DOME
LOADING CHAMBER
SEPARATION PLATE ORIFICE
DOME SEPARATING PLATE
PLUG (FOR EXTERNAL CHARGING)
DIAPHRAGM PLATE
DOME NEEDLE VALVE
DIAPHRAGM
PRESSURE EQUALIZING ORIFICE
CHARGING CONNECTION
DIAPHRAGM PLATE SPRING
RELIEF VALVE
OUTLET
ACTUATING CHAMBER
BODY NEEDLE VALVE
VALVE SEAT
VALVE
VALVE SPRING
CAGE

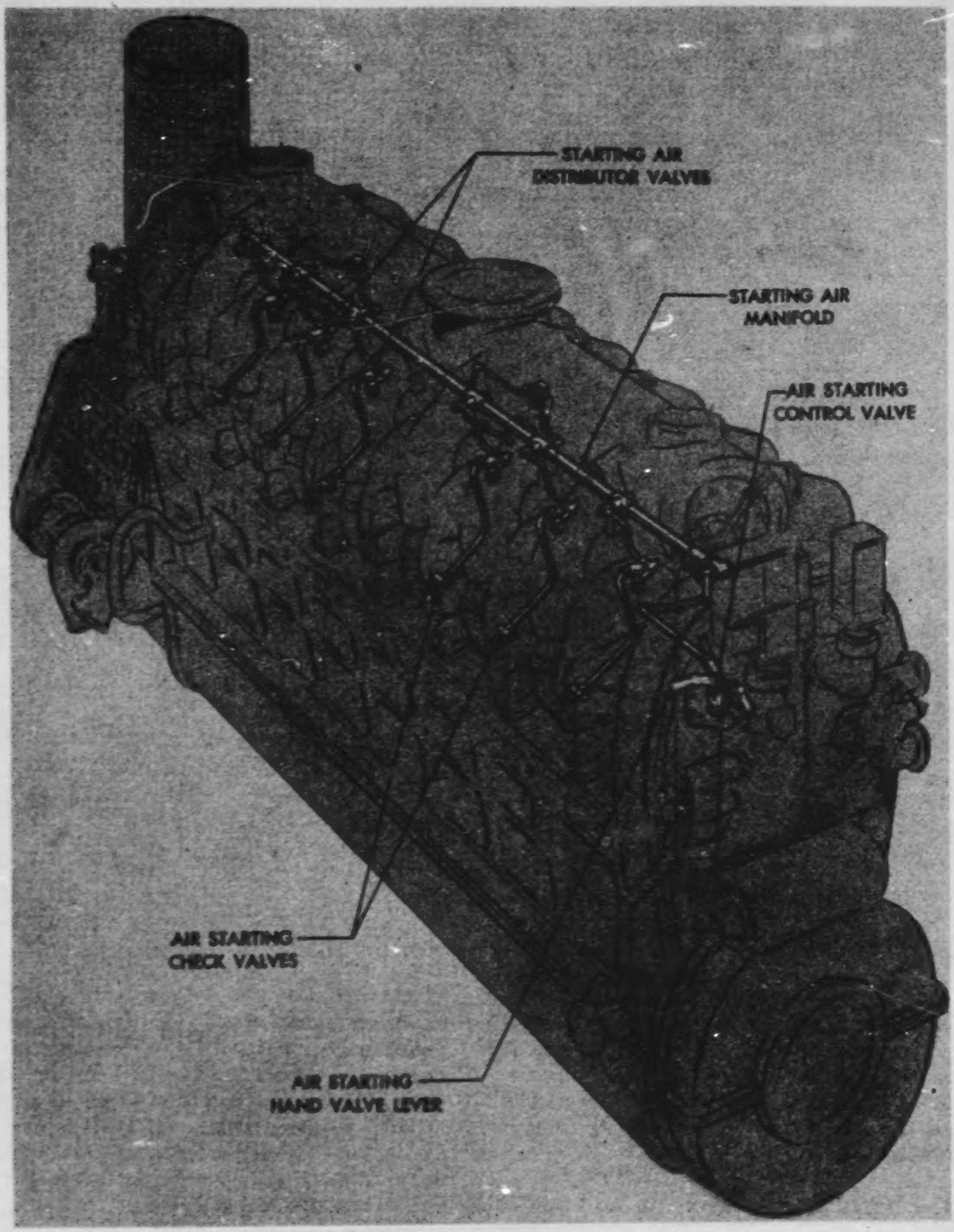
47.61

Figure 7-12.—Regulator valve.

have a thorough knowledge of the mechanism of one air starting system, you should be able to understand the principles of operation of other air starting systems used by the Navy. This section describes the system used on the General Motors engines.

The engine air starting system used on GM engines (fig. 7-13) is known as the separate distributor type because the starting air distributor valve (fig. 7-14) is a separate unit for each cylinder. Each distributor valve is individually operated by its cam on the camshaft. Of the 16 cylinders, 8 are air started, 6 in one bank and 2 in the other, but all of the cylinder heads in both banks are equipped with an air starting check valve so as to maintain full interchangeability. On the cylinders that are not air started, the inlet opening of the check valve is sealed with a removable plug.

Air is supplied to the air starting control valve (fig. 7-13) from the air supply line. When


STARTING AIR DISTRIBUTOR VALVES
STARTING AIR MANIFOLD
AIR STARTING CONTROL VALVE
AIR STARTING CHECK VALVES
AIR STARTING HAND VALVE LEVER

75.180

Figure 7-13.—GM engine air starting system.

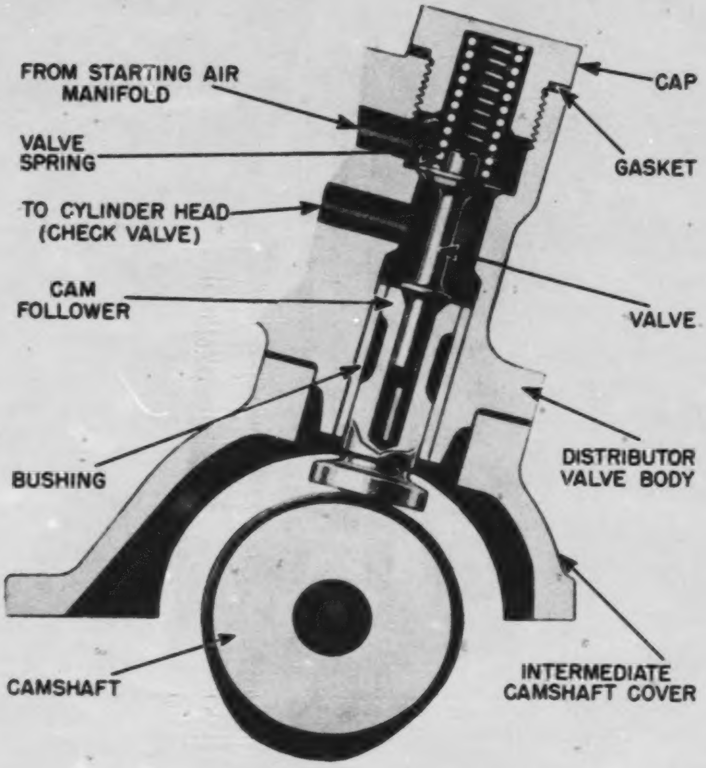
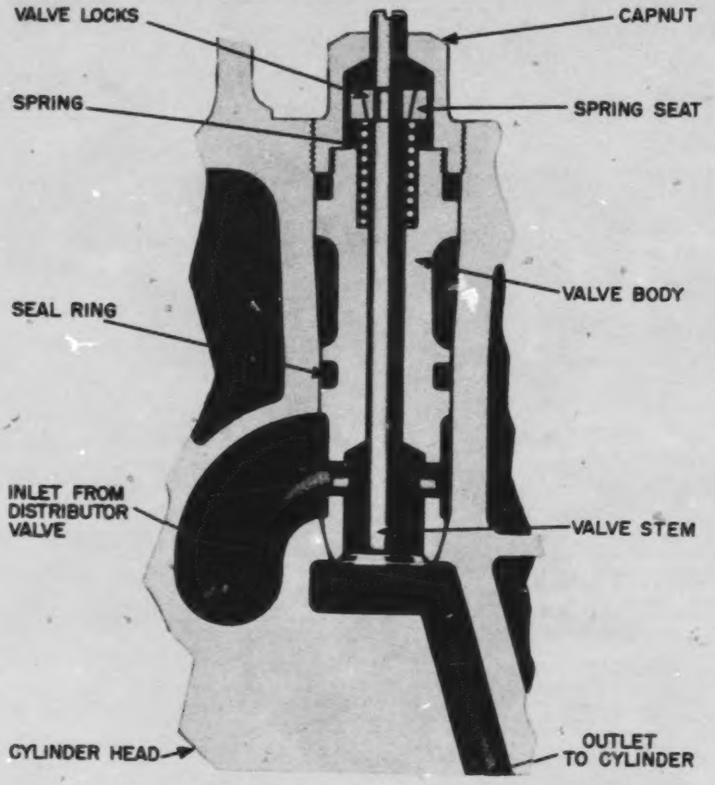

FROM STARTING AIR MANIFOLD
CAP
VALVE SPRING
GASKET
TO CYLINDER HEAD (CHECK VALVE)
CAM FOLLOWER
VALVE
BUSHING
DISTRIBUTOR VALVE BODY
CAMSHAFT
INTERMEDIATE CAMSHAFT COVER
75.181

Figure 7-14.–Starting air distributor valve, GM.

the air starting control valve is opened by a hand lever, air is admitted to the starting air manifold (a steel pipe extending the full length of the top deck of the engine and located below the exhaust manifold). The starting air manifold is connected by air lines to each of the starting air distributor valves. The distributor valves are opened in engine cylinder firing order by their cams on the camshafts, admitting air into the lines that connect each distributor valve to its air starting check valve (fig. 7-15). When the distributor valve admits air into the lines leading to the air starting check valve, the pressure opens the check valve, thereby admitting air into the combustion chamber.

The air pressure moves the pistons and turns the crankshaft until there is sufficient compression for combustion. Combustion pressure and exhaust gases are kept from backing into the air starting system by the check valves. As soon as the engine is firing, the hand lever is released, and spring pressure closes the air starting control valve. This shuts off the supply of starting air to the engine.

The air starting control valve is mounted on a bracket bolted to the camshaft drive cover near the hand control lever. It is a poppet type valve, opened manually by a lever and closed by a spring. A plug in the valve body holds the spring against the valve head. The valve stem guide is a bronze bushing pressed into the body. A spring and head, placed over the valve stem where it projects from the body, returns the hand lever to the valve's closed position. The hand lever and the operating lever stop are



75.182

Figure 7-15.—Air starting check valve, GM.

keyed to a shaft in the bracket. A safety device prevents opening the air starting control valve while the engine jacking gear is engaged.

STARTING AIR DISTRIBUTOR VALVES.—Each of the eight cylinders, which are air started, is equipped with a starting air distributor valve (fig. 7-14). The starting air distributor valves (timing valves) are of the poppet type, with forged steel bodies that bolt to the camshaft intermediate covers. The valve is held closed by spring pressure that bears against the top of the valve and is guided in the hollow end of the cam follower which rides on the camshaft air starting cam. The cam follower is guided in a bronze bushing pressed into the valve body. A lock pin keeps the cam follower in the body.

When cam action opens the valve, starting air passes from the air manifold through a chamber in the valve body above the valve head into a line leading to the air starting check valve in the cylinder head. The cam action opens the valve in the proper valve sequence. The cam follower is lubricated by oil splashed by the cam from the cam pocket.

AIR STARTING CHECK VALVES.—The air starting check valve shown in figure 7-15 is a poppet type valve located in the cylinder head. The valve body fits into a recess in the cylinder and is held in place by a capnut that screws into the cylinder head and bears on top of the valve body. The valve body contains the valve seats and serves as a valve guide. Air is prevented from leaking to the outside of the valve body by a synthetic rubber seal ring located above the inlet port. The valve is closed by a spring surrounding an upper portion of the valve stem. This spring fits into a recess in the valve body and exerts pressure on the spring seat, which is locked to the valve stem by two half-round pieces (valve locks) fitted into a groove on the valve stem. The valve opens into a small chamber (in the cylinder head) with a short, open passage to the cylinder.

When the starting air distributor valve admits air into the line leading to the air starting check valve, the air passes into a chamber above the valve seat. The pressure of this air opens the check valve and allows the air to pass into the cylinder and move the piston. When the air distributor valve closes, the pressure in the valve chamber drops, and spring tension closes the air starting check valve.

When combustion occurs, the air starting check valve remains closed because the pressure in the combustion chamber is greater than the pressure of the starting air that actuates the check valve. This prevents exhaust gases and combustion pressures from backing into the air starting system.

IGNITION AIDS

Ignition in a diesel engine is accomplished by a combination of fuel injection and compression. Diesel engines normally require a longer cranking period than gasoline engines, and at low ambient temperatures, they are more difficult to start because the heat of compression may not be sufficient to ignite the fuel-air mixture. Therefore, at low temperatures it is necessary to preheat the engine by means of an electric air heater or to furnish an auxiliary low ignition-temperature fuel during the starting period by means of a pressure-primer system. The types of air heaters and primers used for starting diesel engines include the (1) grid resistor, (2) flame primer, and (3) ether primer.

GRID RESISTOR

The grid resistor usually consists of a 1200-watt resistance grid mounted on a frame and supported by insulating blocks in the engine air-intake manifold. The grid is preheated by current from the starting battery, before the engine is cranked, and is operated during the cranking period until the engine is running smoothly.

ETHER PRIMERS

The most widely used cold weather starting aid is the ether capsule or the pressurized cylinder type. Both inject a highly volatile fluid into the air-intake system to assist ignition of the fuel.

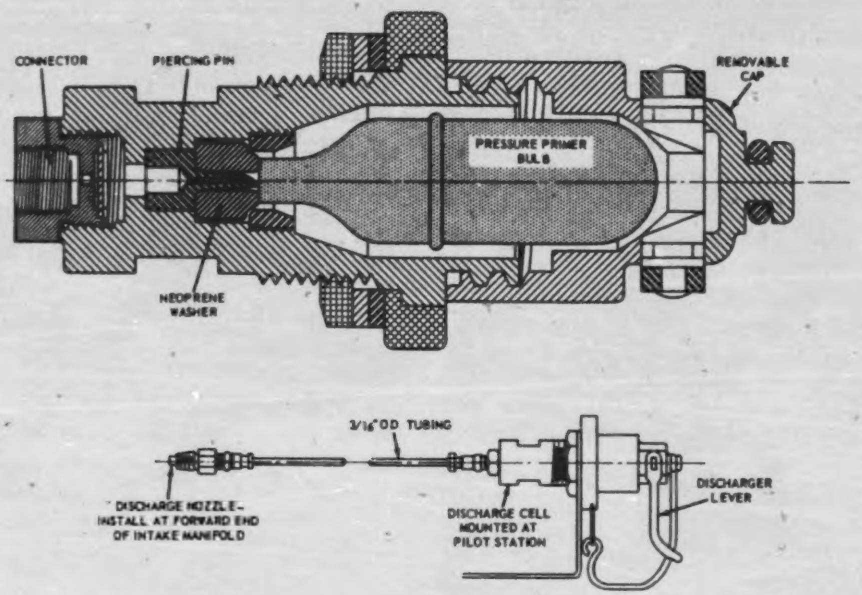
An ether capsule primer (fig. 7-16), consists of a (1) discharger cell, (2) discharger nozzle, and (3) pressure primer bulb that contains a liquid ether mixture. The discharger cell and the discharger nozzle are connected together by a suitable length of 3/16-inch tubing. The discharger cell is a metal enclosure containing a piercing pin and provided with a removable cap for inserting the pressure primer (capsule) bulb. The cap is equipped with a discharger lever. When the lever is operated, it forces the capsule bulb against the piercing pin.

The discharging cell is installed at the control station in a vertical position so that the neck of the capsule bulb is always down toward the piercing pin. The discharger nozzle is installed through a 1/4-inch pipe connection at the forward end of the intake manifold.

When using the ether capsule primer for cold weather starting, press the engine starter switch. As soon as the starting motor brings the engine up to cranking speed, operate the discharger lever to discharge the capsule bulb. Continue cranking while the ether mixture is being sucked rapidly through the connecting tube to the intake manifold. The capsule bulb requires approximately 15 seconds to discharge, and the diesel engine should start during this interval.

The pressurized cylinder starting aid is being installed on many installations. It is usually located in the engine compartment and is operated by a remote cable from the control station or starting compartment.

The assembly consists of a metering valve with a valve lever and a pusher pin built into the valve body. The replaceable pressurized cylinder, approximately 4 inches in diameter and



75.190

Figure 7-16.—Ether capsule primer.

approximately 9 inches in height, is screwed onto the valve body. Due to the large capacity of the cylinder, it does not need to be replaced after each use, as does the capsule-type starting aid.

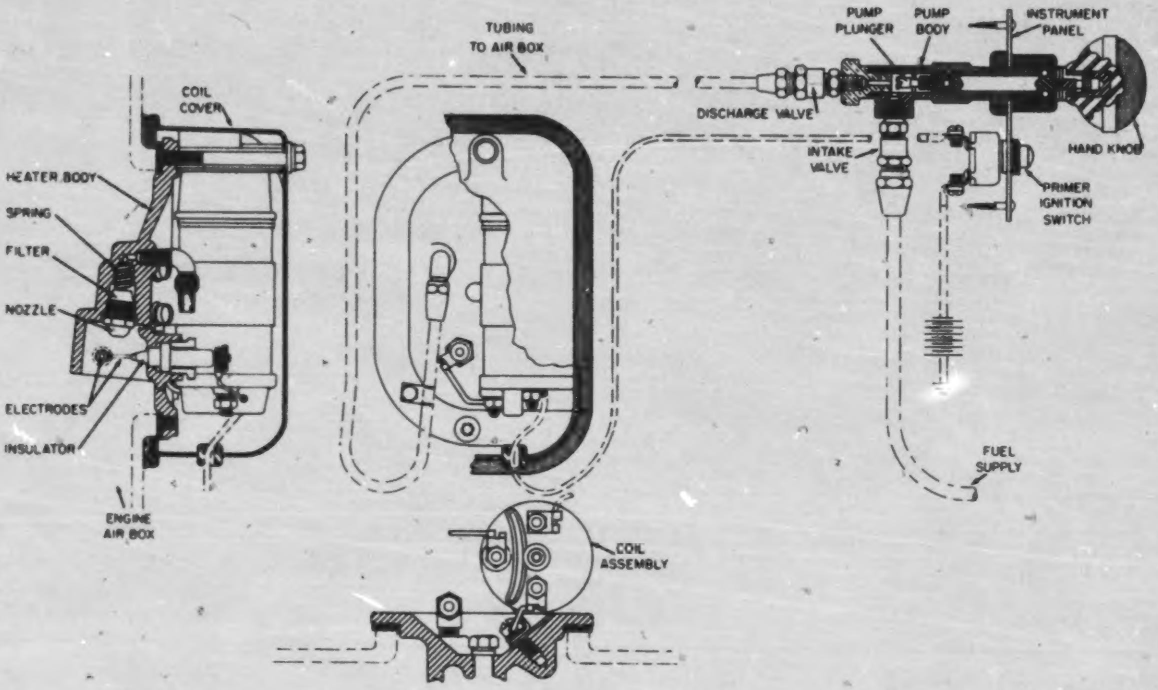
To operate the starting aid, press the engine starter button. Then, pull up on the remote control knob (quick start choke) for 1 to 2 seconds; then, release it. The procedure may be repeated if the engine does not start immediately. (To prevent unnecessary discharge of the cylinder and erratic engine operation, ensure that the choke knob is in the off position after each use.)

FLAME PRIMER

The flame primer (fig. 7-17) is a widely used type of air heater for preheating diesel engines for starting at low temperatures. It is essentially a small, pressure oil burner with electric ignition. The oil is sprayed into the engine air-intake manifold with a manually operated pump and ignited by means of a spark plug, ignition coil, and vibrator. The device consists of two assemblies. The heater unit contains the burner, ignition coil, and vibrator. The other unit is comprised of the pressure pump and ignition switch. The principal advantage of the flame primer is that it imposes a negligible load on the starting battery.

Flame Primer Heater

The heater unit consists of a nozzle, filter, ignition electrodes, and ignition coil with vibrator. One side of the heater body contains the filter, nozzle, and ignition electrodes, and the other side contains the ignition coil, terminals, and connection for the fuel supply. The unit is designed to replace one of the handhole cover plates nearest the center of the engine air box. The entire heater unit is provided with a protective metal cover. The air necessary for combustion is obtained from the charging blower. The products of combustion, including the flame-heated air, are discharged into the engine cylinders (with practically no heat loss), resulting in an immediate response of the engine.


TUBING TO AIR BOX
PUMP PLUNGER
PUMP BODY
INSTRUMENT PANEL
COIL COVER
DISCHARGE VALVE
HAND KNOB
INTAKE VALVE
HEATER BODY
SPRING
FILTER
PRIMER IGNITION SWITCH
NOZZLE
ELECTRODES
INSULATOR
FUEL SUPPLY
ENGINE AIR BOX
COIL ASSEMBLY

75.189

Figure 7-17.—Flame primer.

Pressure Pump and Ignition Switch

The pressure pump and ignition switch (fig. 7-17) are mounted on the instrument panel near the engine starter switch so that both the ignition switch and the engine starter switch can be depressed simultaneously with one hand, thereby leaving the other hand free to operate the pump. The pump supplies fuel under pressure to the heater unit where the charge is filtered before reaching the nozzle. The suction side of the pump is connected either directly to the main fuel tank or to the engine supply line between the main tank and the engine transfer pump. When the pump plunger is not in use, it is held in the IN position by a spring mechanism. The pump plunger is designed so that a pressure of approximately 10 psi on the knob will deliver (from the nozzle) a finely atomized fuel. The fuel is readily ignited by the spark at the electrodes in the heater unit. The rate of travel of the plunger on the pumping stroke is determined by the flow of oil from the discharge nozzle and normally requires 3 or 4 seconds per stroke.

The ignition switch is connected in the line between the starting battery and one terminal of the ignition coil in the heater unit. The other terminal (primary) of the ignition coil is grounded to the engine.

CHAPTER 8

ENGINE COOLING SYSTEMS

A great amount of heat is generated within an engine during operation. Combustion produces the greatest portion of this heat; compression of gases within the cylinders and friction between moving parts add to the total amount of heat developed within an engine. Since the temperature of combustion alone is about twice that at which iron melts, it is apparent that, without some means of dissipating heat, an engine would operate for only a very limited time.

Of the total heat supplied to the cylinder of an engine by the burning fuel, only approximately one-third is transformed into useful work; an equal amount is lost to the exhaust gases. This leaves approximately 30% to 35% of the heat of combustion which must be removed to prevent damage to engine parts. Heat, which may produce harmful results, is transferred from the engine through the mediums of water, lubricating oil, air, and fuel. The water of the cooling system removes the greater portion (approximately one-fourth) of the heat generated by combustion. The balance of the heat (usually less than 10% is removed from the engine by the lubricating oil, the fuel, and the air.

If the heat lost through cooling could be turned into work by an engine, the output of the engine would be almost doubled. However, the loss of valuable heat is necessary in order for an engine to operate. Without proper temperature control, the lubricating oil film between moving parts would be destroyed, proper clearance between parts could not be maintained, and metals would fail.

MAINTAINING ADEQUATE LUBRICATION

The need for maintaining a film of lubricating oil on pistons, cylinder walls, and the contacting surfaces of other moving parts of an engine is discussed in chapter 9 of this manual. The oil film must be maintained if adequate lubrication is to be provided. The formation of such an oil film depends, to a large degree, on the viscosity of the oil. If the engine cooling system did not keep the engine temperature below a specified level, viscosity would be reduced to a point where the oil film might be destroyed, resulting in insufficient lubrication, and consequent excessive wear of parts. Also, the heat absorbed by the lubricating oil from the combustion process and from friction in bearings must be removed to retard oxidation of the oil and resulting sludge formation.

Prevention of overheating is generally thought of as the primary function of an engine cooling system; however, it is possible that a cooling system might remove too much heat. If an engine is operated at too low a temperature, condensation takes place, causing acids and sludge to form in the lubricating oil. Also, cylinder temperatures must be maintained high enough to minimize the condensation of corrosive gases on the cylinder walls. Excessively low operating temperatures will increase ignition lag, which causes detonation. Thus, it is apparent that the cooling system of an engine must maintain the operating temperatures within a specified range. The range of operating temperatures for a given engine is found in the applicable manufacturer's technical manual.

PREVENTING EXCESSIVE VARIATION IN DIMENSIONS

In addition to lubricating oil troubles, other difficulties may occur if the cooling system does not maintain operating temperatures within a specified range. Great differences between operating temperatures at varying loads cause, through contraction and expansion, excessive changes in the dimensions of engine parts. Excessive changes also occur when there are large differences between the cold and the operating temperatures of the parts. These changes in dimensions result in a variation in clearances between the moving parts. Under normal operating conditions, these clearances are very small; any variation in the dimensions of the moving parts may cause insufficient clearances and subsequent inadequate lubrication, increased friction, and possible seizure.

RETAINING THE STRENGTH OF METALS

By removing heat from an engine, the cooling system helps to prevent deterioration of the metal in the engine parts. If the parts, such as liners, pistons, valves, and bearings are allowed to overheat, the tensile strength will be materially reduced, thereby accelerating wear and increasing the probability of failure. If overheating is sufficiently severe, the affected part will melt.

High temperatures change the strength and physical properties of the various metals used in an engine. For example, if a cylinder head is subjected to excessively high temperatures, the tensile strength of the metal is reduced; the probability of fracture or cracking is thereby increased. Such high temperatures also cause excessive expansion of the metal, which may result in shearing of the cylinder-head bolts.

TYPES OF COOLING SYSTEMS

In a marine engine, the cooling system which functions to keep engine parts and fluids at safe operating temperatures may be of the open or closed type. In the open system, the engine is cooled directly by saltwater. In the closed system, freshwater (or antifreeze) is circulated through the engine. The freshwater is then cooled by saltwater. In marine installations, the closed system is most commonly used; however, some older marine installations use an open type system.

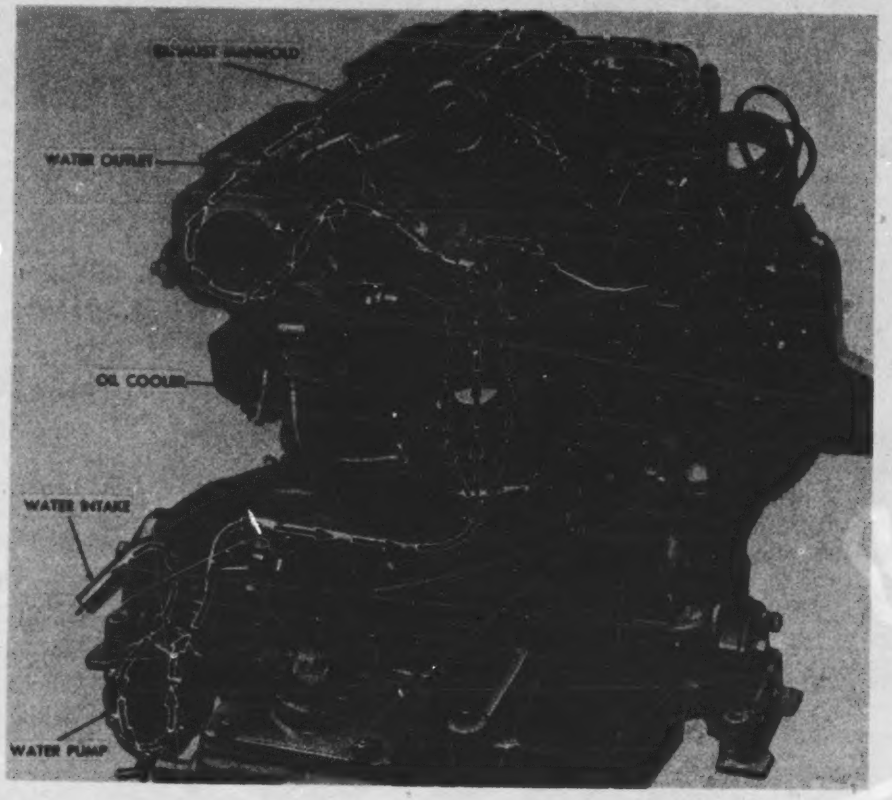
The cooling systems of diesel and gasoline engines are similar both mechanically and in the function performed. For these reasons, much of the information which follows is applicable to the cooling systems of both types of engines.

THE OPEN COOLING SYSTEM

The term "open" means that the liquid (used for cooling purposes in the open system) is drawn directly from the water in which the boat or ship operates, is passed through the system, and is then discharged overboard. The open system is sometimes called the "raw" water system, because the water is untreated and generally contains contamination, whether the water is drawn from the sea, a lake, or a river. However, since the majority of the Navy's boats and ships operate in seawater, the open-type cooling system is generally referred to as the "seawater" or "saltwater" system, regardless of the system's source of water.

In open cooling systems, the sequence of parts and passages through which the water flows may vary slightly between engines. In a typical open system, the saltwater is drawn from the sea through a sea chest or scoop, through sea valves, a strainer, a pump, and a lube oil cooler. It is then circulated through the engine and discharged overboard. In some installations the strainer is located in the pump discharge line.

The oil cooler acts as a heat exchanger; the heat from the oil circulating through the cooler is transferred to the water passing through the cooler. Thus, the temperature of the oil is lowered and the temperature of the intake water is raised before the water passes into the engine cooling passages.



75.205

Figure 8-1.—An open cooling system.

From the cooler, the water passes through water jackets and passages within the engine, cooling such parts as the cylinder liners, the block, and the head or heads. After cooling the various parts of the engine, the water passes through the exhaust silencer water jackets and then discharges overboard. In some engines, water flows through the exhaust silencer water jackets before it flows through the engine passages. Thus, the heat from the lubricating oil and the exhaust gases is used to raise the temperature of the engine's intake water. The path of cooling water through one arrangement of an open cooling system is shown in figure 8-1.

The open cooling system has several disadvantages, the most important being the exposure of the engine to scale formation, marine growth and dirt deposits in the piping, and the fluctuating temperature of seawater. Scale and deposits restrict water flow in the engine water passages and also act as insulation which hinders heat transfer to the cooling water. Scale and deposits therefore prevent adequate cooling of engine parts, which may result in serious difficulties.

THE CLOSED COOLING SYSTEM

The closed-type cooling system of a marine engine actually consists of two entirely separate circuits (sometimes called systems)—a freshwater (distilled) circuit and a saltwater circuit. The freshwater circuit is a self-contained system, similar to the cooling system in the engine of an automobile. One of the primary differences between the freshwater circuit of a marine installation and that of an automobile is that the marine installation incorporates a cooler rather than a radiator. Saltwater carries away the heat in a marine closed system instead of air as in an automobile. The flow of liquid through the two circuits of one type of closed cooling system is illustrated in figure 8-2.

In some marine installations a separate saltwater circuit is not included in the closed cooling system. In such installations, the freshwater cooler is located on the outside of the hull, well below the waterline, in direct contact with the seawater. Such a hull-mounted unit is called a keel cooler.

In the freshwater cooling circuit, the freshwater is reused continuously for cooling the engine. The order of the parts through which water flows in the freshwater circuit of a closed cooling system is not always the same. In a majority of the installations, however, the water is circulated throughout the engine cooling spaces by an attached circulating freshwater pump. The water then flows to a freshwater cooler, where it is cooled by the saltwater cooling circuit. After it leaves the cooler, the freshwater may or may not, depending on the installation, go through the lubricating oil cooler to act as a cooling agent for the lubricating oil. The water finally returns to the suction side of the freshwater pump, completing the circuit.

The saltwater circuit of the closed-type cooling system consists of an attached saltwater pump (usually similar to the freshwater pump), which draws saltwater from the sea through a sea chest, strainer, and sea valves and discharges it through the freshwater cooler. (In some installations an additional strainer is located in the pump discharge.) From the freshwater cooler, the seawater may or may not, depending on the installation, pass through the lubricating oil cooler before it is discharged overboard. The overboard discharge performs varying functions, depending on the individual installation. Normally, it is used to cool the engine exhaust piping and the silencer.

On some engine-generator units, the attached saltwater pump furnishes saltwater to the generator air coolers as well as freshwater coolers and returns the water to the overboard discharge. Throttling valves are frequently placed in lines to the freshwater cooler and the generator air coolers to control the flow of water through these heat exchangers.

PRINCIPAL PARTS OF A CLOSED COOLING SYSTEM

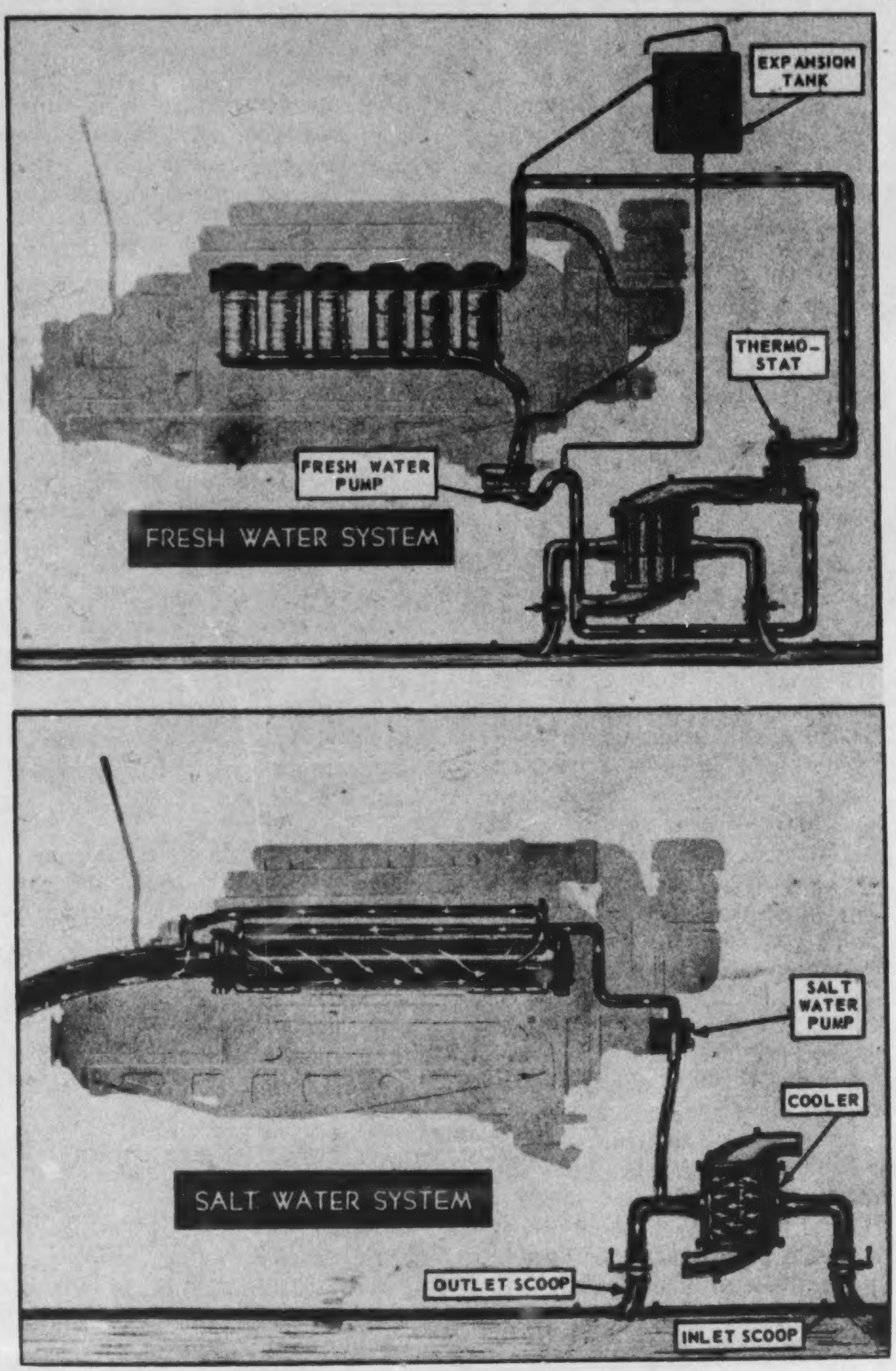
The closed cooling system of an engine may include such parts as pumps, coolers, engine passages, water manifolds, valves, expansion tank, piping, strainers, connections, and instruments. Some of these parts and their locations on one type of engine are shown in figure 8-3. The schematic diagrams in figure 8-4 and 8-5 show the parts and the path of water flow in the freshwater and seawater circuits of one arrangement of a closed cooling system. Note in figure 8-4 that two pumps, one for each bank of cylinders, are provided and that the lubricating oil cooler is located in the freshwater circuit.

Even though there are many types and models of engines used by the Navy, the cooling systems of most engines include the same basic parts. Design and location of parts, however, may differ considerably from one engine to another. The following discussion points out some similarities and differences to be found in the various parts of a closed engine-cooling water system.

PUMPS

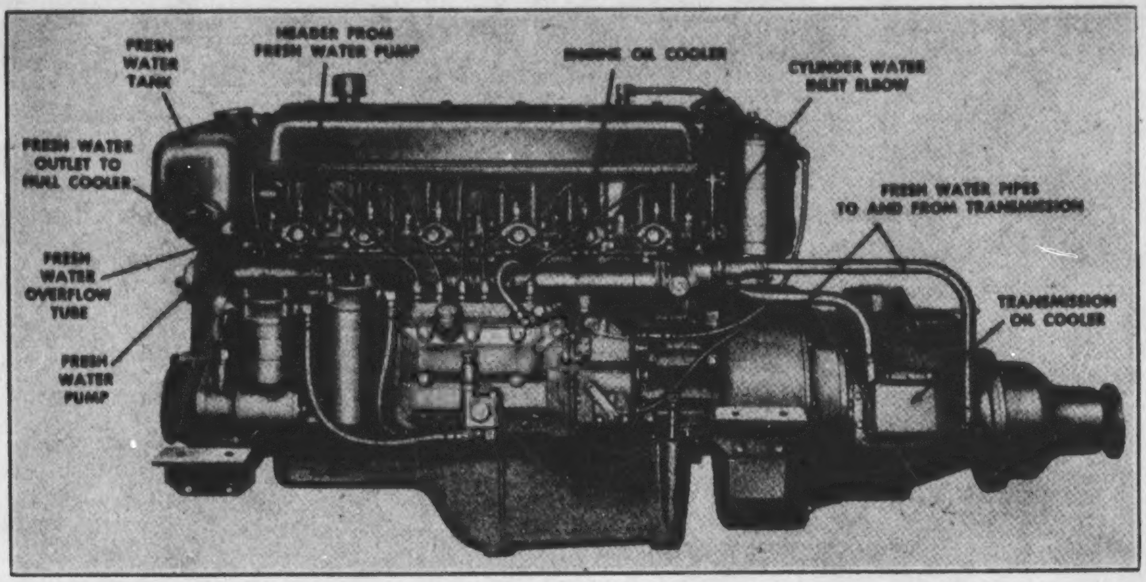
All engine cooling systems have an attached freshwater pump. Some installations also have a detached auxiliary pump.

The attached pump is used to keep the water circulating through the cooling system. Since attached pumps are engine-driven, it is


EXPANSION TANK
THERMOSTAT
FRESH WATER PUMP
FRESH WATER SYSTEM
SALT WATER PUMP
COOLER
SALT WATER SYSTEM
OUTLET SCOOP
INLET SCOOP

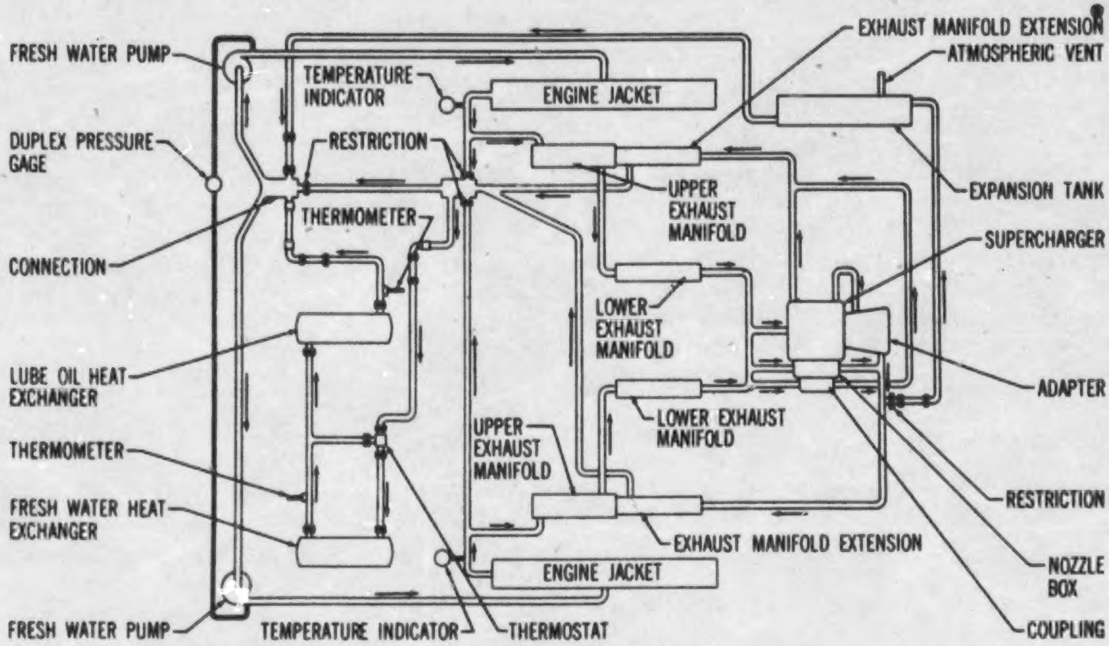
75.206

Figure 8-2.—A closed type cooling system with freshwater and saltwater circuits.


FRESH WATER TANK
HEADER FROM FRESH WATER PUMP
ENGINE OIL COOLER
CYLINDER WATER INLET ELBOW
FRESH WATER OUTLET TO HULL COOLER
FRESH WATER PIPES TO AND FROM TRANSMISSION
FRESH WATER OVERFLOW TUBE
TRANSMISSION OIL COOLER
FRESH WATER PUMP

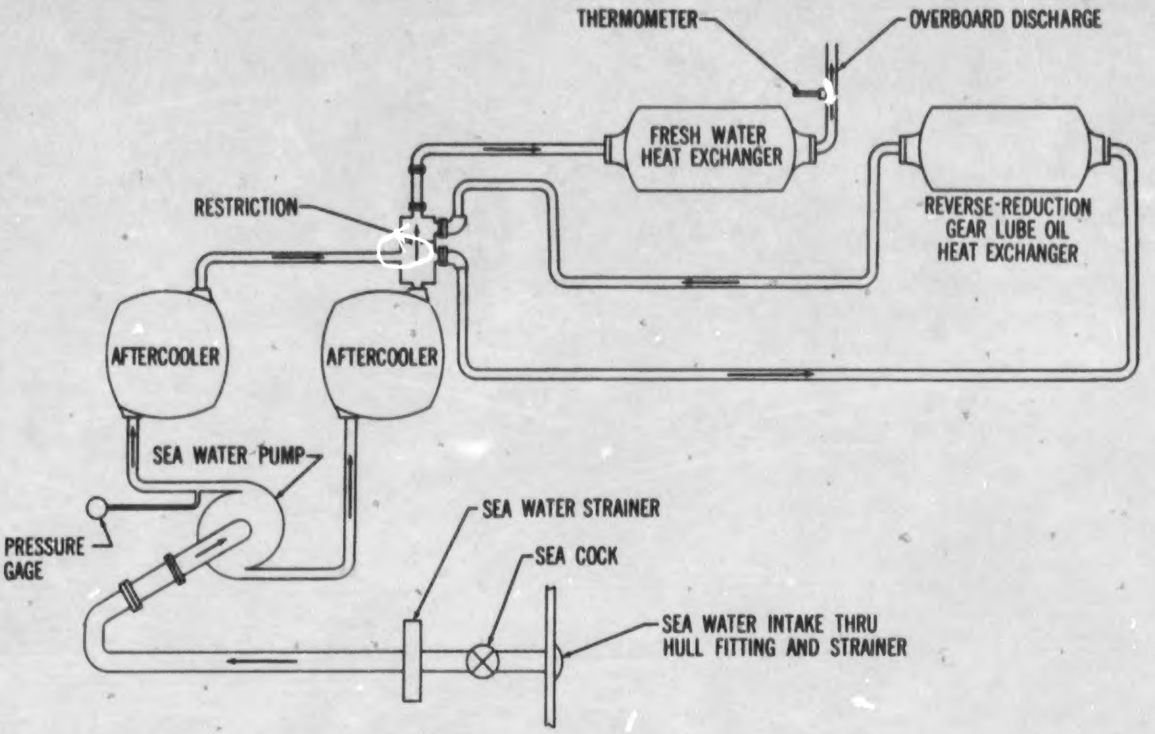
75.207

Figure 8-3.–Parts of a cooling system (Gray Marine, Six-D427).


FRESH WATER PUMP
TEMPERATURE INDICATOR
ENGINE JACKET
EXHAUST MANIFOLD EXTENSION
ATMOSPHERIC VENT
DUPLEX PRESSURE GAGE
RESTRICTION
UPPER EXHAUST MANIFOLD
EXPANSION TANK
THERMOMETER
CONNECTION
SUPERCHARGER
LOWER EXHAUST MANIFOLD
LUBE OIL HEAT EXCHANGER
ADAPTER
LOWER EXHAUST MANIFOLD
THERMOMETER
UPPER EXHAUST MANIFOLD
RESTRICTION
FRESH WATER HEAT EXCHANGER
EXHAUST MANIFOLD EXTENSION
ENGINE JACKET
NOZZLE BOX
FRESH WATER PUMP
TEMPERATURE INDICATOR
THERMOSTAT
COUPLING

75.208

Figure 8-4.–Freshwater circuit of a closed cooling system.


THERMOMETER
OVERBOARD DISCHARGE
FRESH WATER HEAT EXCHANGER
RESTRICTION
REVERSE-REDUCTION GEAR LUBE OIL HEAT EXCHANGER
AFTERCOOLER
AFTERCOOLER
SEA WATER PUMP
PRESSURE GAGE
SEA WATER STRAINER
SEA COCK
SEA WATER INTAKE THRU HULL FITTING AND STRAINER

75.209

Figure 8-5.—Saltwater circuit of a closed cooling system.

impossible for cooling water to be circulated in the engine after the engine has been stopped or in the event the attached pump fails. For this reason, some engines are equipped with an electric-driven (detached) auxiliary pump, which may be used if either the freshwater pump or the saltwater pump fails. An auxiliary pump may also be used as an after-cooling pump, when an engine has been secured.

Differences Between Freshwater and Saltwater Pumps

The pumps used in the freshwater and saltwater circuits of an engine cooling system may, or may not, be of the same type. In some systems, the pumps in both circuits are identical. In other systems, where pumps are of the same type but where variations exist, the principal differences between the pumps of the two circuits are in size and capacity. In the cooling system of some engines, the saltwater pump has a capacity almost double that of the freshwater pump.

Types of Pumps

Centrifugal pumps and gear pumps are the principal types of pumps used in engine cooling systems. On some engines, a rotary type pump in which the impeller has flexible vanes is used in the saltwater circuit. The basic principles of operation of these types of pumps are given in *Fireman*, NAVEDTRA 10520-E.

Centrifugal pumps are more common in engine cooling systems than pumps of other types, particularly in large diesel engines. Centrifugal pumps are of various types. They may be separately driven or attached to the engine, single or double suction, open or closed impeller, reversible or nonreversible, etc. In all centrifugal pumps, however, water is drawn into the center of the impeller and thrown at high velocity into the casing surrounding the impeller, where the velocity decreases and pressure increases correspondingly.

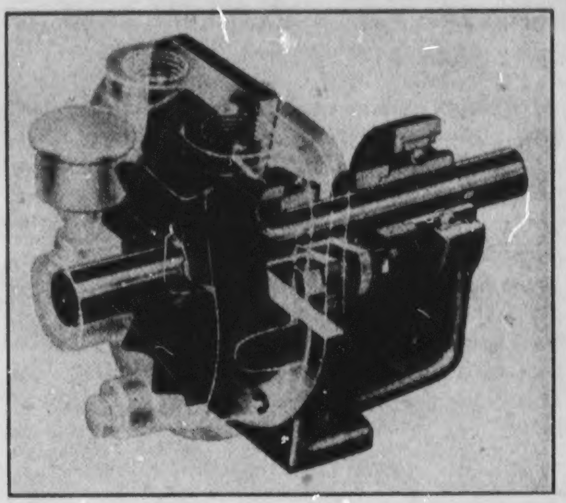
In all such pumps, sealing devices, usually of the mechanical seal type, are provided to prevent leakage of water, oil, grease, or air around the impeller shaft.

Generally, the clearances between the impeller and the casing must be small to reduce the internal leakage. Wear rings are frequently used between the impeller and the casing so that the desired small clearances, when lost, may be regained by replacing these rings. The rings are designed to take most of the wear. The routine maintenance of pumps is covered in chapter 15 of this manual.

Pump Location and Method of Drive

Depending on the engine and the type of installation, the location of the pumps and the method of drive will vary. Note that in the upper diagram of figure 8-2 the freshwater pump is mounted on the bottom of the lower crankcase at the supercharger end of the engine. The pump is gear-driven at 1 1/2 times engine speed. The saltwater pump of the same engine (lower diagram in figure 8-2) is mounted on the supercharger housing. The saltwater pump is driven from the supercharger drive shaft through a coupling shaft; it operates at crankshaft speed.

In the engine shown in figure 8-3, the freshwater pump is located in a housing mounted on the bottom of the water (expansion) tank. The pump is pulley-driven with a V-belt by the crankshaft. The saltwater pump (not shown in fig. 8-3), used only for exhaust cooling in the Gray Marine Six-D427, is mounted on the front of the engine and is belt-driven by the crankshaft. A phantom view of the saltwater pump, showing the impeller and the bearings, is shown in figure 8-6.



75.210
Figure 8-6.–Phantom view of a rotary type saltwater pump.

In some models of the FM opposed-piston engine, the freshwater pump and the saltwater pump are located on opposite sides of the engine, at the control end. The pumps of the FM engine are driven by the lower crankshaft, through the flexible-drive coupling which also drives the fuel and lubricating pumps and the governor. In the GM 16-278A, the cooling-system pumps are mounted on opposite sides of the blower housing and are driven by the crankshaft, through the accessory-drive gear train. The freshwater pump on the GM 6-71 is mounted on the front end of the blower and is driven by the lower blower rotor shaft, through a coupling. The examples given here are only a few of many which could be given to illustrate the variations in pump location and method of drive. Regardless of location and drive, the pumps keep the water circulating through the system to dissipate heat and to keep operating temperatures within safe limits. Most of the excess heat developed by an engine is transferred from the freshwater circuit and the lubricating oil to the saltwater circuit, through coolers.

COOLERS (HEAT EXCHANGERS)

As a Fireman, you learned that devices which transfer heat from one fluid to another are called heat exchangers; also, that these devices may be used as either heaters or coolers and that the same device can be used for both purposes. In internal-combustion engines, heat exchangers are used primarily for cooling. For this reason, the devices used in engines for cooling a hot fluid (liquid or gas) by transferring heat to a cooler fluid are commonly referred to as coolers.

Fluids Cooled

Coolers are used in Navy engines principally to cool freshwater and lubricating oil. Sometimes coolers are used to reduce the temperatures of engine intake air and generator cooling air. In most marine engine installations, the freshwater in the engine cooling system is cooled by saltwater. Lubricating oil and air may be cooled by saltwater or by freshwater, depending on the installation. Thus, on the basis of the fluids cooled, you will encounter freshwater coolers, lubricating oil coolers, and air coolers. All coolers operate on the same principle; coolers used in various installations and for the cooling of various fluids may differ however in appearance and in details of design.

Classification (General) of Coolers

Coolers may be classified in several ways: by the relative direction of flow of the two fluids (parallel flow, counterflow, and crossflow types); by the number of times either fluid passes the other fluid (single-pass and multipass types); by the path of heat (indirect-contact, or surface, type and direct-contact type); and by general construction features of the unit (shell-and-tube type and jet, or mixer, type). The coolers used in cooling systems of engines are commonly identified on the basis of construction features.

Types of Coolers

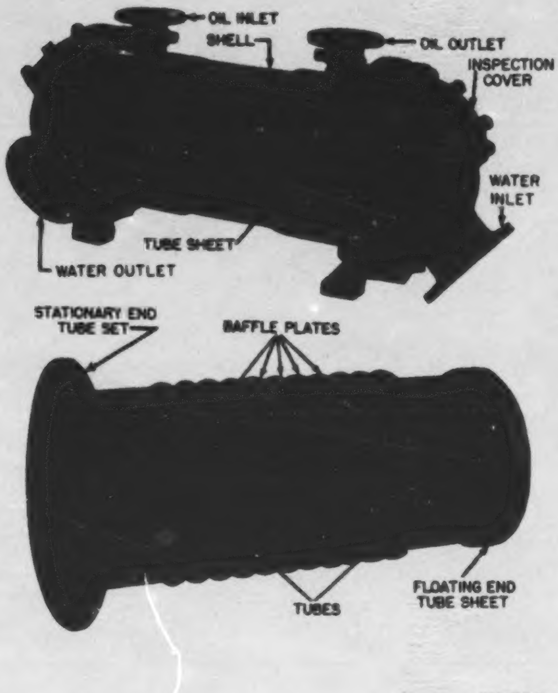
On the basis of classification by construction features, a cooler is either the shell-and-tube type or the jet type. In jet-type coolers, the hot and cold fluids enter the unit, are mixed, and are then discharged as a single fluid. Since this feature is not desirable in engine cooling, the coolers used with engines are of the shell-and-tube type. In a shell-and-tube cooler, the hot and cold fluids are prevented from mixing by the thin walls of the tubes of the element.

The shell-and-tube type is a general classification which includes all coolers in which the two liquids are prevented from mixing. Modifications of the shell-and-tube cooler have resulted in two other types of coolers: the strut-tube cooler and the plate-tube cooler. These coolers are of the shell-and-tube type in that the fluids are prevented from mixing; however, due to design features, the coolers used in engines are commonly identified as being either strut-type or plate-tube type.

SHELL-AND-TUBE COOLERS.—The cooling systems of many engines are equipped with coolers of the shell-and-tube type. Coolers of this type are frequently referred to as Ross-type coolers. Shell-and-tube coolers are used to cool lubricating oil and freshwater. Coolers used for cooling lubricating oil are somewhat smaller than those used to cool water. One model of a shell-and-tube cooler is shown in figure 8-7.

The shell-and-tube cooler consists principally of a bundle (also called a bank or nest) of tubes encased in a shell. The cooling liquid generally flows through the tubes. The liquid to be cooled enters the shell at one end, circulates around the tubes, and is discharged at the opposite end of the shell. In other coolers of this type the cooling liquid flows through the shell and around the tubes; the liquid to be cooled passes through the tubes.

The tubes of the cooler are attached to the tube sheets at each end of the shell; this



47.74A

Figure 8-7.—Shell-and-tube cooler.

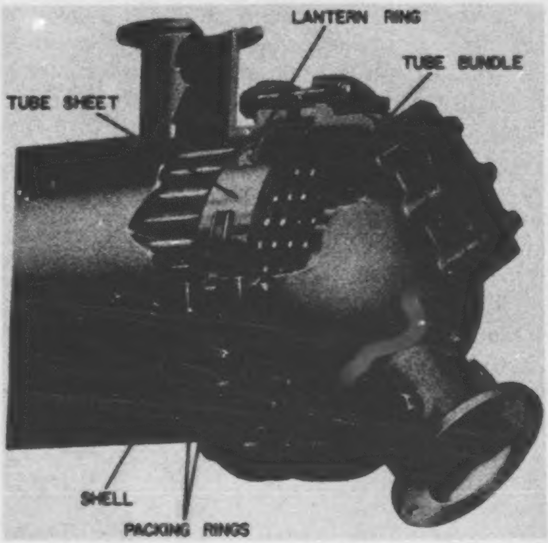
arrangement forms a tube bundle which can be removed as a unit from the shell. The ends of the tubes are expanded to fit tightly into the holes in the tube sheets; they are flared at their outer edges to prevent leakage.

One tube sheet and a bonnet are bolted to the flange of the shell. The sheet is referred to as the stationary-end tube sheet. The tube sheet at the opposite end "floats" in the shell, which allows for expansion of the tube bundle. Packing rings, which prevent leakage past the floating-end tube sheet, are fitted at the floating end between the shell flange and the bonnet. The packing joint allows for expansion and prevents the mixing of the cooling liquid with liquid to be cooled inside the shell, by means of a leak-off, or lantern, gland which is vented to the atmosphere. The details of a floating end of a shell-and-tube cooler are shown in figure 8-8.

Transverse baffles are arranged around the tube bundle in such a manner that the liquid is directed from side to side as it flows around the tubes and through the shell. The deflection of the liquid ensures the maximum cooling effect. Several of the baffles serve as supports for the bank of tubes; these baffles are of heavier construction than those which only deflect the liquid.

The flow of the liquid in the tubes is opposite that of the liquid flow in the shell. On this basis, the cooler could be classified as the counterflow type. Since heat transfer is through the walls of the tubes, the cooling liquid enters one end of the cooler, flows directly through the tubes, and leaves at the opposite end; however, the cooler could be more precisely classified as a single-pass, indirect-type cooler.

STRUT-TUBE COOLERS.—The majority of the coolers used in the cooling systems of marine engines are the strut-tube type. The strut-tube cooler has an advantage over the shell-and-tube cooler in that it provides considerable heat transfer in a smaller and more compact unit. On the other hand, the shell-and-tube cooler, while larger for an equivalent amount of heat transfer, has an



47.74B

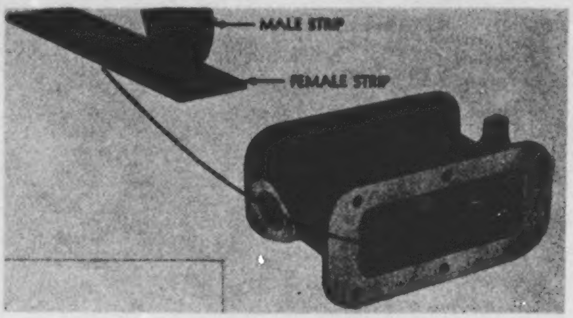
Figure 8-8.—Floating end of a shell-and-tube cooler.

advantage over the strut-tube cooler in that it is able to withstand a higher degree of scaling and larger foreign particles without clogging the cooling system. Strut-tube coolers are commonly referred to as Harrison-type coolers; however, manufacturers other than Harrison produce coolers of the strut-tube type. The term radiator is also sometimes used to identify coolers with strut-tube construction.

There are many different designs of strut-tube coolers. The tube assemblies of two of these coolers, and the type of tube construction in each, are illustrated in figures 8-9 and 8-10.

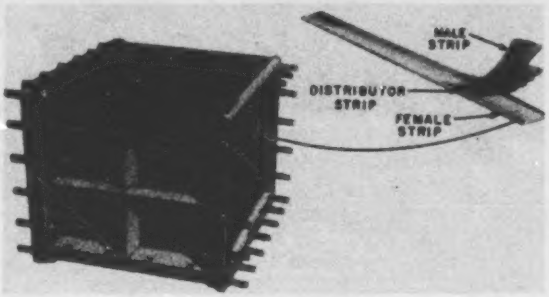
Strut-tube coolers are used for cooling water and lubricating oil. Water coolers and oil coolers differ principally in design and in size of the tubes. (See fig. 8-9 and 8-10.) Each of the tubes in both oil coolers and water cooler is composed of two sections, or strips. In the strut-tube water cooler both sections of each tube contain either a series of formed dimples or cross tubes brazed into the tubes. These "struts" (sometimes referred to as baffles) increase the inside and outside contact surfaces of each tube and create turbulence in the liquid flowing through the tube; thus, the heat transfer from the liquid being cooled to the cooling liquid is increased. The struts also increase the structural strength of the tube. In the oil cooler, the tubes are from one-half to one-third as large as the tubes of water coolers, and the sections of the tubes do not contain either dimples or cross tubes. Instead, a distributor strip, which serves the same purpose as the struts in the tubes of the water cooler, is enclosed in each tube.

The tubes of a strut-tube cooler are fastened in place with a header plate at each end, and are further secured with an intermediate reinforcement plate. These plates are electroplated with tin to protect the iron parts of the cooler. The tube-and-plate assembly (sometimes called the tube bundle or the core assembly) is mounted in a bronze frame. The frame and the core assembly fit in the cast metal casing, or housing, and are held in place by the two end covers. The casing, core assembly, frame, covers, and other parts of one model of a strut-tube cooler are shown in figure 8-11.



47.75

Figure 8-9.—Tube assembly of a strut-type water cooler (Harrison).



75.213

Figure 8-10.—Tube assembly of a strut-tube lubricating oil cooler (Harrison).

The header plates, at the ends of the tubes, separate the cooling-liquid space in the casing from the cooled-liquid ports in the end covers. The cooled liquid flows through the tubes in a straight path from the cover inlet port to the cover discharge port at the opposite end of the cooler. The intermediate tube plate acts as a baffle to create a U-shaped path for the cooling liquid, which flows around the outside of the tubes from the inlet opening of the casing to the discharge opening.

PLATE-TUBE COOLERS.—Shell-and-tube coolers and strut-tube coolers are used for cooling both oil and water, usually with seawater as a coolant; plate-tube coolers, however, are used only for cooling oil. Seawater or freshwater may be used as the cooling liquid

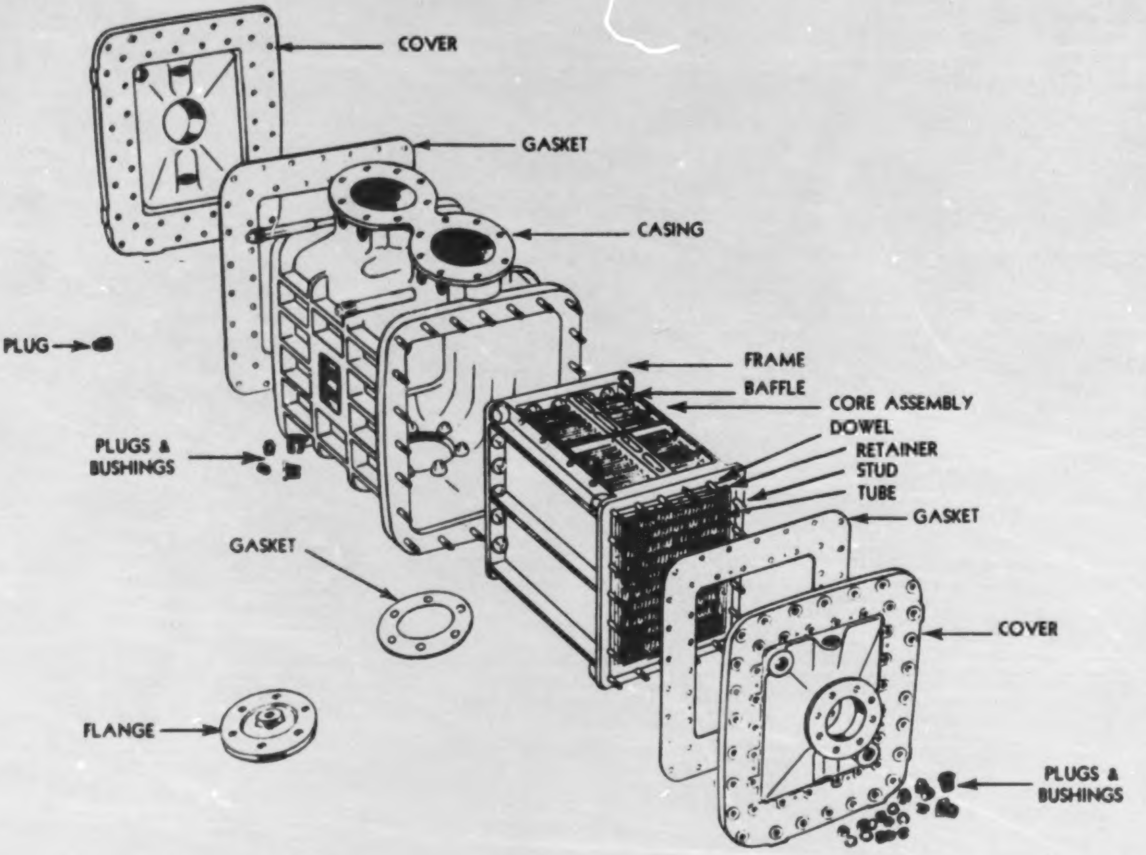

COVER
GASKET
CASING
PLUG
FRAME
BAFFLE
CORE ASSEMBLY
DOWEL
RETAINER
STUD
TUBE
GASKET
PLUGS & BUSHINGS
GASKET
COVER
FLANGE
PLUGS & BUSHINGS
75.214

Figure 8-11.—Parts of a strut-tube cooler (Harrison).

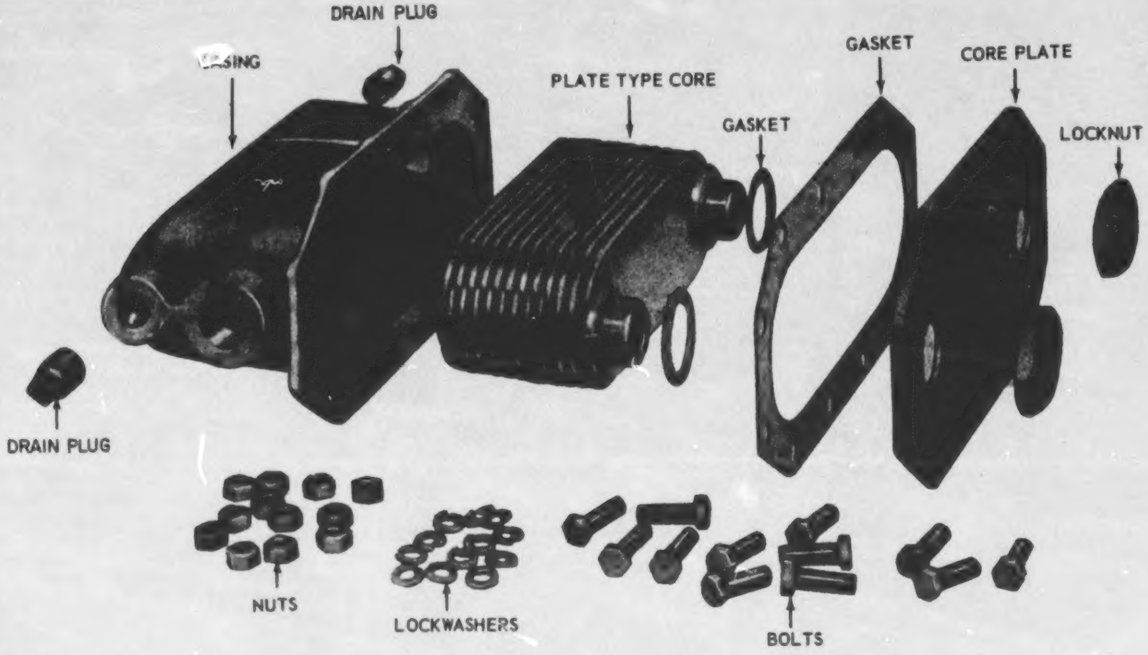
in plate-tube coolers, depending on the installation. An exploded view of one model of a Harrison plate-tube cooler is shown in figure 8-12.

A plate-tube cooler consists of a stack of flat, oblong, plate-type tubes which are connected in parallel with the oil supply and enclosed in a cast metal housing. Each tube of a plate-tube cooler consists of two sections, or stampings, of copper-nickel. A distributor strip is enclosed in each tube. Several tubes are assembled to form the cooling element, or core, of the cooler. A plate-type core and tube construction are shown in figure 8-13.

In a plate-tube cooler, the cooling liquid flows through the casing and over the tubes. The heated oil flows through the tubes. The tubes in the core assembly are spaced so that the cooling water circulates freely over their external surfaces.

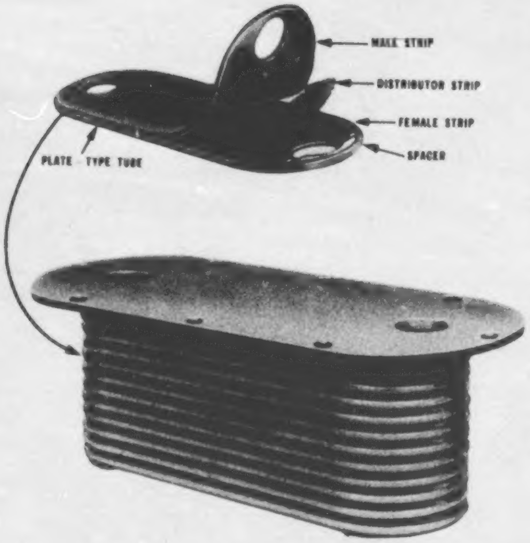
Location of Coolers

The location of coolers will vary, depending on the engine and the fluid cooled. Some coolers are attached; others are detached. An example of a detached freshwater cooler is shown in figure 8-2. The freshwater cooler used with the engine shown in figure 8-3 is also detached. Some freshwater coolers are located on the outside of the hull, well below the waterline.


DRAIN PLUG
CASING
PLATE TYPE CORE
GASKET
GASKET
CORE PLATE
LOCKNUT
DRAIN PLUG
NUTS
LOCKWASHERS
BOLTS

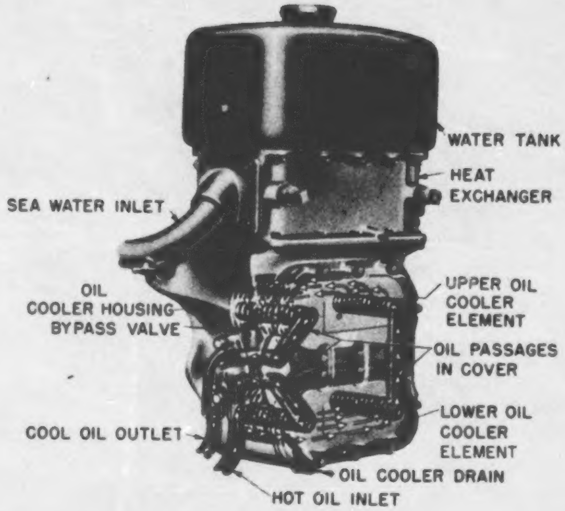
75.215

Figure 8-12.—Plate-tube cooler (Harrison).


MALE STRIP
DISTRIBUTOR STRIP
FEMALE STRIP
SPACER
PLATE - TYPE TUBE

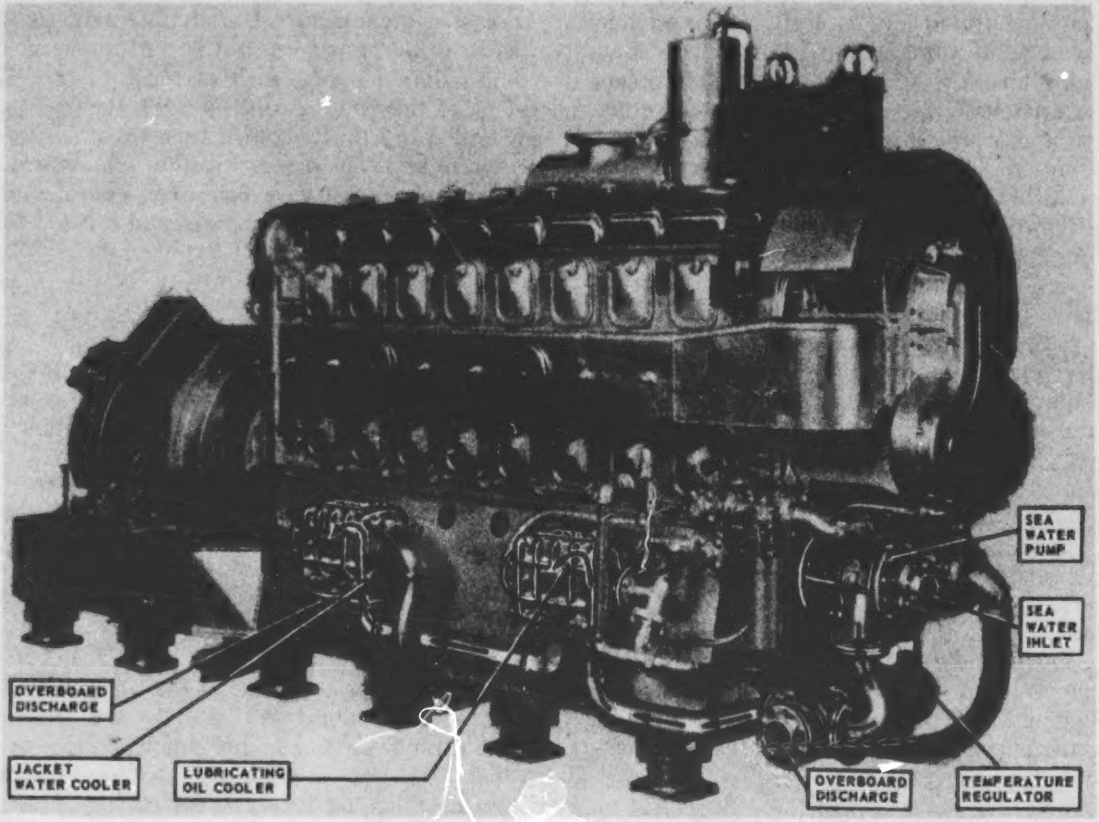
47.75.2

Figure 8-13.—Plate type core and tube construction (Harrison).


WATER TANK
HEAT EXCHANGER
SEA WATER INLET
OIL COOLER HOUSING
BYPASS VALVE
UPPER OIL COOLER ELEMENT
OIL PASSAGES IN COVER
LOWER OIL COOLER ELEMENT
COOL OIL OUTLET
OIL COOLER DRAIN
HOT OIL INLET

75.216X

Figure 8-14.—Location of coolers and other cooling system components of GM series 71 engines.



75.217X

Figure 8-15.–Location of coolers and other cooling system components of GM 8-268A engines.

When so located, coolers are frequently referred to as "outboard," "keel," or "hull" coolers.

Examples of variations in the locations of attached freshwater coolers and lubricating oil coolers can be seen in figures 8-1, 8-3, 8-14, and 8-15. Note that the lubricating oil cooler of the open system (fig. 8-1) is attached to the engine block and is located between the saltwater intake and the exhaust-manifold water jacket. The engine shown in figure 8-3 has two lubricating oil coolers: one for engine oil; the other for transmission oil. Freshwater serves as the cooling liquid in both coolers. The location of the freshwater coolers and the lubricating oil coolers of the GM series 71 engines (fig. 8-14) is representative of cooler location in many small diesel engines. How the location of the coolers in a medium-sized diesel differs from that in smaller engines is shown in figure 8-15.

The coolers discussed up to this point have been those used in lowering the temperature of freshwater and lubricating oil. In some engines, the temperature of the supercharged intake air is also reduced. If the temperature of this air, which is heated by compression within the supercharger, is reduced, the amount of air charge entering the cylinder during each intake event will increase and the power output of the engine will be increased. Coolers used for lowering the temperature of the intake air are shell-and-tube and strut-tube types and operate on the same principle as coolers used for cooling freshwater and lubricating oil. Air coolers, used to cool intake air, are referred to as intercoolers and aftercoolers. Intercoolers are located before the supercharger, and aftercoolers are located between the supercharger and the intake manifold. The heated air from the supercharger passes through the tubes, where the heat is transferred to the cooling water flowing around the outside of the tubes. Cooling water is generally from the seawater circuit but may be from the freshwater circuit.

The engine cooling system is also used to cool the air around some engine-generator sets. Generators, unlike internal-combustion engines, cannot be directly cooled by liquids. If a generator develops more heat than can be removed by the surrounding air, a supply of cool air must be provided to remove the excess heat. Where generator air-cooling is necessary, an air cooler is provided in a closed air circuit. The heated air from the generator is forced through the cooler, where the temperature is reduced; the air is then recirculated to the generator. Depending on the installation, either freshwater from the engine cooling system or seawater may serve as the cooling medium.

ENGINE WATER PASSAGES

The form, location, and number of cooling passages within an engine vary considerably in different engines. The form of a cooling water passage and its location are controlled by many factors, such as size of engine, cycle of operation, and cylinder arrangement. Many of the water passages found in various engines have been illustrated and mentioned earlier in this manual in connection with engine parts. Additional information on engine cooling passages is given in the following paragraphs. The examples we used for illustrative purposes are not all-inclusive; however, those described are representative of the passages to be found in in-line, V-type, and opposed-piston engines.

Cylinder Heads

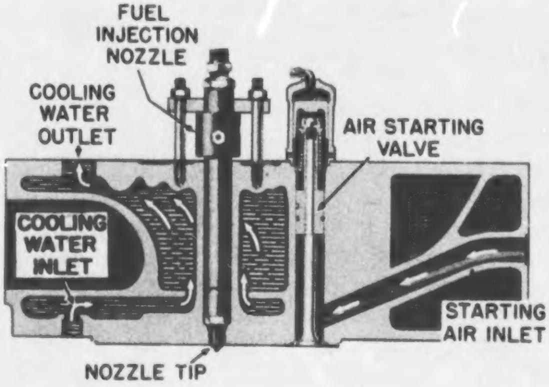
Most engines have cooling-water passages within the cylinder head(s). The passages in cylinder heads generally surround the valves and, in diesels, the injectors. Usually, the passages are cast or drilled as an integral part of the head. In some cylinder heads, such as those of the GM 6-71 and the Gray Marine 64-HN9, the injectors are sealed in a water-cooled tube by means of a neoprene seal. The passages in the cylinder heads of two in-line engines which differ considerably in size are shown in figures 8-16 and 8-17.

Cylinder Liners or Blocks

The passages in the cylinder head(s) receive water from a jacket or from passages, either of which may be an integral part of the cylinder liners or the cylinder block. Water flow to the cylinder head is almost always upward from the liner or block.

Water Manifolds and Jackets

The location and form of the water passages in a V-type engine are basically the same as those found in an in-line engine. Differences which exist are generally due to the cylinder arrangement. The location and form of these passages at one point in a V-type engine are shown in the cross-sectional view of the GM 16-278A (fig. 8-18).



75.219

Figure 8-16.—Water passages and path of flow in cylinder head.

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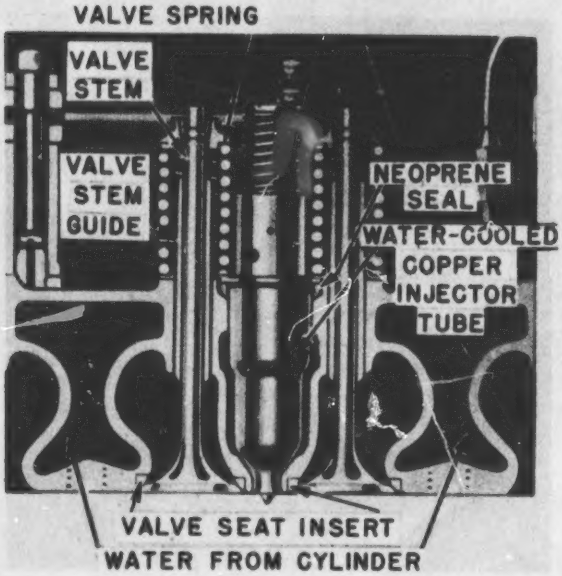

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Figure 8-17.–Water passages in cylinder head of a Gray Marine engine.

Note the location (in fig. 8-18) of the two freshwater manifolds. These manifolds receive water from the freshwater pump. From the manifolds, the water flows into cylinder liner passages and then through the cylinder head passages. From the cylinder head passages, the water flows through the water jackets of the exhaust elbows and the exhaust manifold. The water is forced from the exhaust-manifold water jacket through a cooler before it is recirculated through the system by the pump.

Because of differences in engine design, the location and form of the cooling passages in an opposed-piston engine will differ, to a degree, from those in other types of engines. The lack of cylinder heads eliminates some of the passages common to engines of the in-line and V-types. While differences of a minor nature exist in the passages of different types of engines, the cooling passages of all engines are similar in many respects. Some ways in which the passages of an opposed-piston engine are similar to those of other types of engines are shown in figure 8-19

Note that in the FM engine the exhaust manifolds are encased in water jackets similar to those of the GM-16-278A (fig. 8-18). The liner passages of the FM 38D8 1/8 are similar to those found in other types of engines. The location of the water header (manifold) differs in various engines. In such engines as the GM-16-278C (fig. 8-18), the water manifold receives water from the pump. In these engines, water from the manifold flows through the liner- and head-passages and then on to cool and exhaust manifold before it flows through the cooler and back to the pump. In the FM 38D8 1/8, the water from the pump usually enters the engine through the water jackets of the exhaust elbows and the exhaust manifolds; in some engines, water enters the cylinder liner through a nozzle-adapter. In the usual arrangement, the water header or manifold in the FM 38D8 1/8 receives water from the cylinder-liner water passages (fig. 8-19). In other words, the water header of an FM 38D8 1/8 is the last passage in the engine through which water flows before it goes through the cooler and back to the pump; in the GM 16-278A the water header (manifold) is the first part to receive water from the pump.

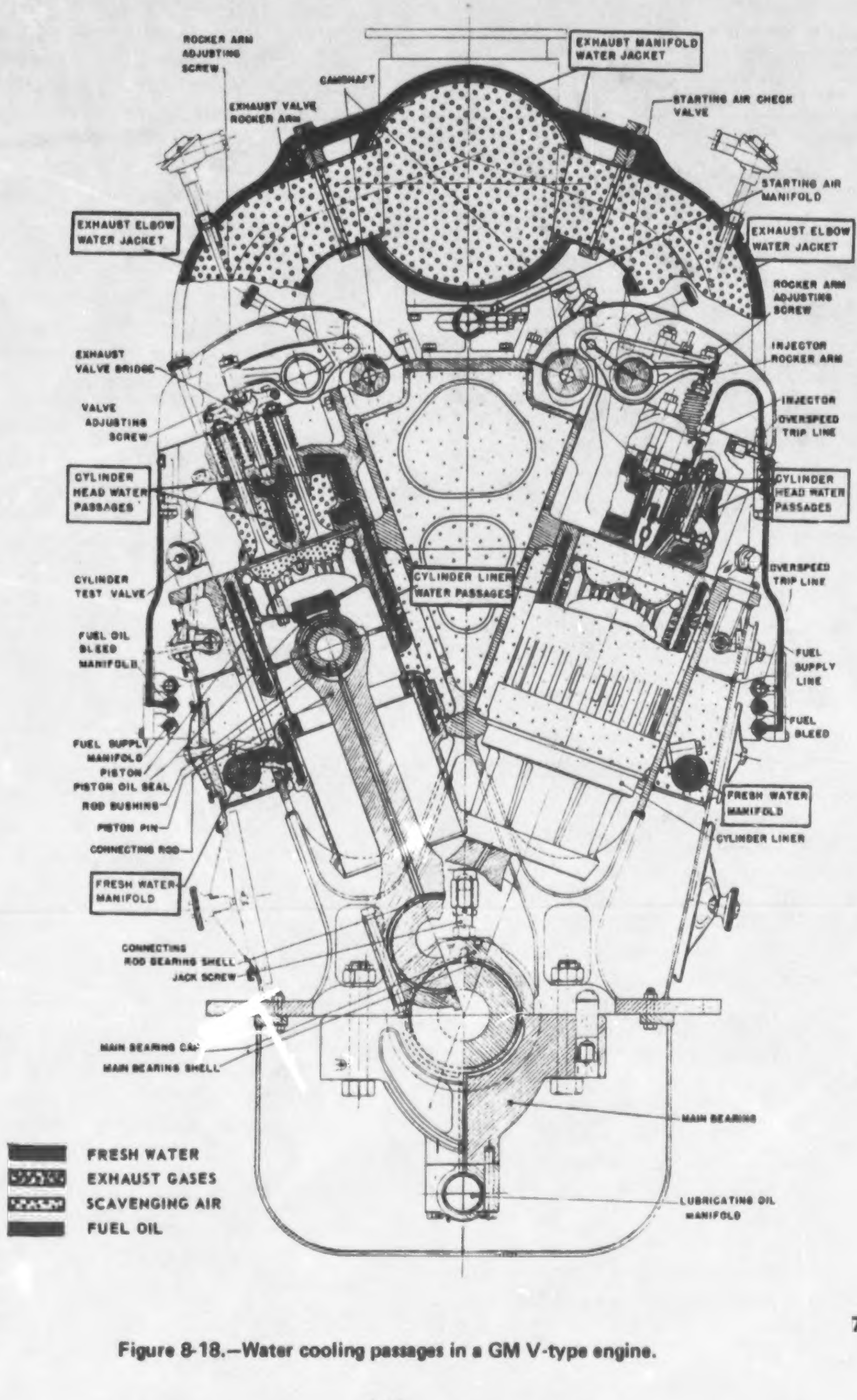
FRESHWATER (EXPANSION) TANKS

The freshwater circuit of an engine cooling system includes a tank which is commonly referred to as the expansion tank. Some expansion tanks are identified as the SURGE TANK or SUPPLY TANK.

The freshwater tank provides a place where water may be added to the system when necessary and provides a space to accommodate changes in water volume which result from the expansion and contraction caused by heating and cooling the water. The piping arrangement of a cooling system permits excess water in the system to pass back to the tank as the water expands upon becoming warm and permits water from the tank to flow into the system when the water contracts as it cools and when the water becomes low because of leakage in the system.

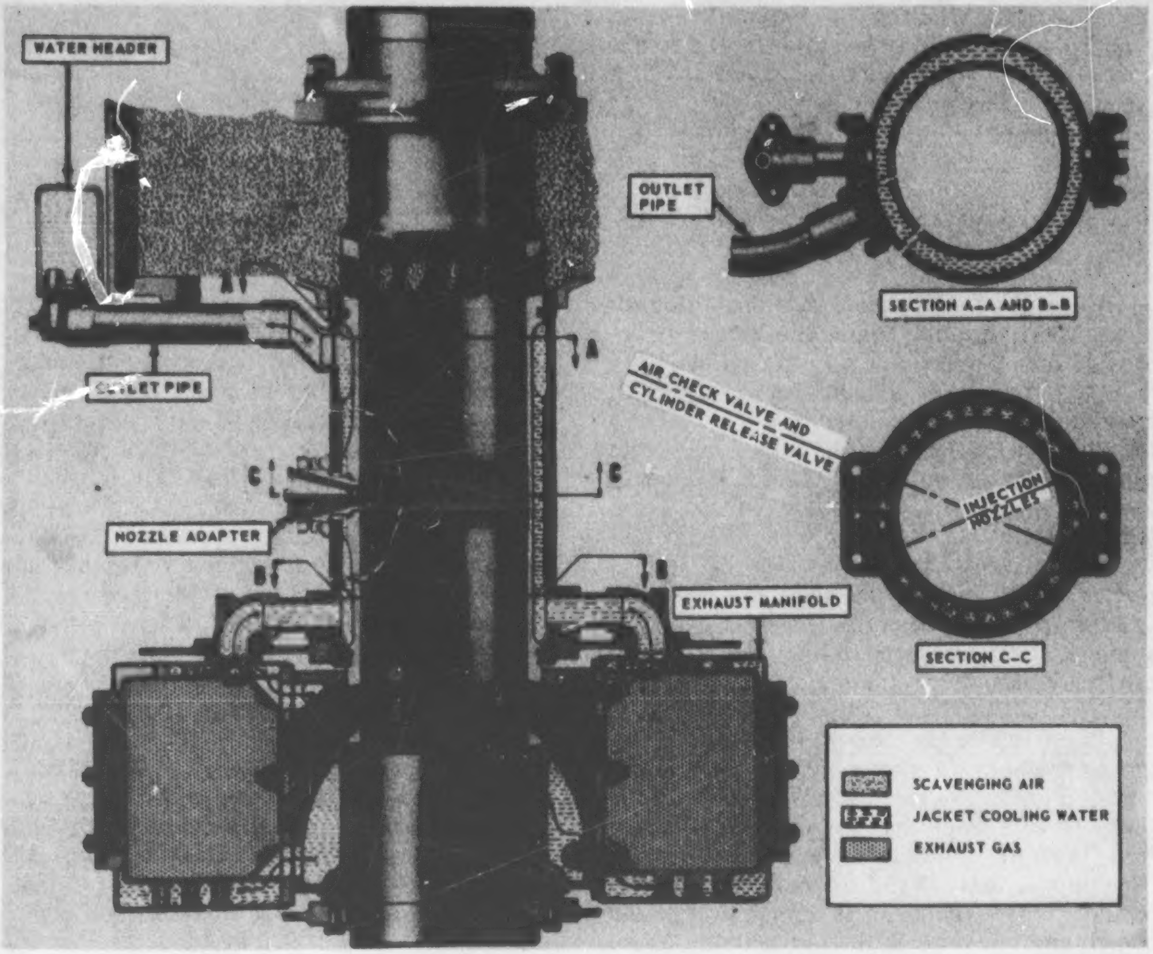
Location of Freshwater Tanks

Even though the exact locations of expansion tanks vary in different engines, the


ROCKER ARM ADJUSTING SCREW
EXHAUST MANIFOLD WATER JACKET
CAMSHAFT
EXHAUST VALVE ROCKER ARM
STARTING AIR CHECK VALVE
STARTING AIR MANIFOLD
EXHAUST ELBOW WATER JACKET
EXHAUST ELBOW WATER JACKET
ROCKER ARM ADJUSTING SCREW
INJECTOR ROCKER ARM
EXHAUST VALVE BRIDGE
VALVE ADJUSTING SCREW
INJECTOR
OVERSPEED TRIP LINE
CYLINDER HEAD WATER PASSAGES
CYLINDER HEAD WATER PASSAGES
CYLINDER TEST VALVE
CYLINDER LINER WATER PASSAGES
OVERSPEED TRIP LINE
FUEL OIL BLEED MANIFOLD
FUEL SUPPLY LINE
FUEL BLEED
FUEL SUPPLY MANIFOLD
PISTON
PISTON OIL SEAL
ROD BUSHING
PISTON PIN
CONNECTING ROD
FRESH WATER MANIFOLD
CYLINDER LINER
FRESH WATER MANIFOLD
CONNECTING ROD BEARING SHELL
JACK SCREW
MAIN BEARING CAP
MAIN BEARING SHELL
MAIN BEARING
LUBRICATING OIL MANIFOLD
FRESH WATER
EXHAUST GASES
SCAVENGING AIR
FUEL OIL

75.221X

Figure 8-18.—Water cooling passages in a GM V-type engine.


WATER HEADER
OUTLET PIPE
SECTION A–A AND B–B
OUTLET PIPE
A
AIR CHECK VALVE AND CYLINDER RELEASE VALVE
C
C
INJECTION NOZZLES
NOZZLE ADAPTER
B
B
EXHAUST MANIFOLD
SECTION C–C
SCAVENGING AIR
JACKET COOLING WATER
EXHAUST GAS

75.222X

Figure 8-19.–Cooling-water passages in an FM opposed-piston engine.

tank is always located at or near the highest point in the circuit. Examples of tank location are shown in figures 8-2, 8-3, and 8-14.

Venting in the Freshwater Circuit

The manner in which venting is accomplished in the freshwater circuit of a cooling system will vary, depending on the engine. However, venting generally involves the expansion tank. In some expansion tanks, particularly in the systems of larger engines, a vent pipe from the high point of the circuit carries to the tank any steam or air bubbles which may form in the system. When steam comes in contact with the cooler water in the tank, the steam condenses back into water. The condensation keeps the system free from steam or air pockets. The expansion tank is vented to the atmosphere. A gage glass, located on the side of the tank, reveals the water level.

In many small engines, the freshwater circuit has no vent and operates under a slight pressure (fig. 8-14); this arrangement confines the water vapor, thus preventing the loss of water. The only escape for water vapor from a circuit which operates under pressure is through a small overflow pipe.

SEA SCOOPS AND STRAINERS

All seawater circuits include either scoops or a sea chest, located below the waterline, to provide the seawater necessary to cool the water in the freshwater circuit. A strainer is incorporated in the seawater circuit to prevent the entrance of seaweed and other debris. In some seawater circuits, two strainers (inboard and outboard) are installed. The outboard strainer covers the seawater inlet; the inboard strainer prevents small particles of foreign matter which passed through the outboard strainer from entering the circuit. Seawater strainers have removable strainer baskets which can be withdrawn for cleaning.

An example of one type of scoop arrangement is shown in figure 8-2. Two scoops, inlet and outlet, are located in the bottom of the ship. These scoops may be opened or closed from controls located in the engineroom. When the ship is underway, its movement forces seawater into the inlet scoop, through the cooler, and out through the outlet scoop. When the ship is not underway and the engines are idling, the outlet scoop is closed and seawater is drawn in through the inlet scoop and cooler by the saltwater pump.

VALVES

The temperatures in the cooling system must be regulated to meet operating conditions. One of the principal factors affecting the proper cooling of an engine is the rate of flow of water through the cooling system. The more rapid the flow, the less danger there is of scale deposits and hot spots, since the high water velocity has a scouring effect on the metal surfaces of the cooling passages which causes the heat to be carried away more quickly. As the velocity of the circulating water is reduced, the discharge temperature of the cooling water becomes higher and more heat is carried away by each gallon of cooling water circulated. As the rate of circulation is increased, each gallon of cooling water carries away less heat and the discharge temperature of the cooling water drops; a relatively cool-running engine results.

The temperature of engine cooling water may be controlled by two methods. In one method, the water temperature is controlled by regulating the amount of water discharged by the pump into the engine. The other method of temperature control involves regulating the amount of water which passes through the freshwater cooler. The first method may be accomplished by means of a manually operated throttling valve; the latter method is generally accomplished automatically by means of a thermostatically operated bypass valve.

Manually Operated Throttling Valve

When the manually operated throttling valve is located in the pump discharge, the valve may be used to cause the water to pass through the engine slowly and be discharged at a high temperature or to pass through the engine rapidly and be discharged at a low temperature. If the pump is driven by an electric motor, these same effects on the velocity and the discharge temperature of the cooling water can be obtained by increasing and decreasing the speed of the pump. Throttling-valves may be used in the seawater circuit to regulate the amount of water passing through the seawater side of the freshwater cooler.

An example of temperature control by means of a throttling valve in the seawater circuit is shown in figure 8-2, lower illustration. In some installations of the system shown, engine temperature in both the open and closed circuits is controlled by opening or closing the throttling valve in the inlet scoop. In other installations of the system shown, temperature is controlled automatically by a thermostatically

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operated bypass valve (upper illustration, fig. 8-2). Where throttling valves are incorporated in the seawater circuit and a thermostatically operated valve is included in the freshwater circuit, the throttling valves are used only to provide a constant flow of seawater or to close the circuit completely. Temperature is then controlled by the action of the thermostatically operated valve in the freshwater circuit. The throttling valve in the saltwater circuit should be adjusted to maintain the minimum flow of saltwater consistent with maintaining proper temperatures in the freshwater circuit and the lubricating oil system.

Thermostatically Operated Bypass Valves

In modern, marine engine installations, automatic temperature control by means of thermostatically operated bypass valves is more common than control by means of throttling valves in the pump discharge or in the seawater circuit. The thermostatic valves used in the cooling systems of engines are of two types: the conventional type (an example of this type is shown in the upper illustration of fig. 8-2); and the three-way proportioning type. Valves of the latter type are commonly called automatic temperature regulators. Conventional thermostatic valves are generally used in small engines; the automatic temperature regulators are commonly used in medium and large engines.

The element is similar in both types of thermostatic valves. The element is so designed that it will expand or contract, dependent on the temperature to which it is exposed. The element of a thermostatic valve may be filled with a gas or a liquid, or it may be of the bimetal type. In most marine engines, the elements of thermostatic valves are either gas-filled or liquid-filled. The elements of conventional thermostatic valves generally contain a gas; the elements of automatic regulators usually contain a volatile liquid, such as ether or alcohol. Elements, constructed in the form of a sealed bellows, may be made of copper, brass, or Monel metal. These metals are used because they are corrosion-resistant and because they will withstand a considerable amount of flexing without fatiguing. The element is attached to a valve which opens and closes as the bellows expands and contracts under the influences of variations in the temperature of the coolant; thus, the amount of water flowing through the line is automatically regulated.

Conventional thermostatic valves may be built into the engine, or they may be located outside the engine within the freshwater circuit as illustrated in the upper portion of figure 8-2. The manner in which a conventional thermostatic valve operates is illustrated in figure 8-20.

As long as the engine and the water are cool, the thermostatic valve remains closed; the water from the engine then flows around the bellows, down through the holes in the valve, and out through the bypass outlet to the freshwater pump (fig. 8-20A). Freshwater is thus bypassed around the cooler until the water gets warm enough to cause the thermostatic valve to open. As the water gets warmer, the increase in temperature causes the element to expand; the valve is then partially opened, a part of the water goes through the cooler, and the rest of the water goes through the bypass outlet (fig. 8-20B). Finally, when the valve is wide open, as a result of the increase in the temperature of the water, the valve seats on the base of the thermostat housing. The flow of freshwater through the bypass outlet is then stopped, and all the water from the engine passes through the cooler where the temperature of the water is reduced (fig. 8-20C).

Automatic Regulating Valve

In many engines, freshwater temperature is regulated by an automatic regulating valve which maintains the freshwater temperature at any desired value by bypassing a portion of the water around the freshwater cooler. An automatic temperature regulator of the type commonly used in the cooling systems of marine

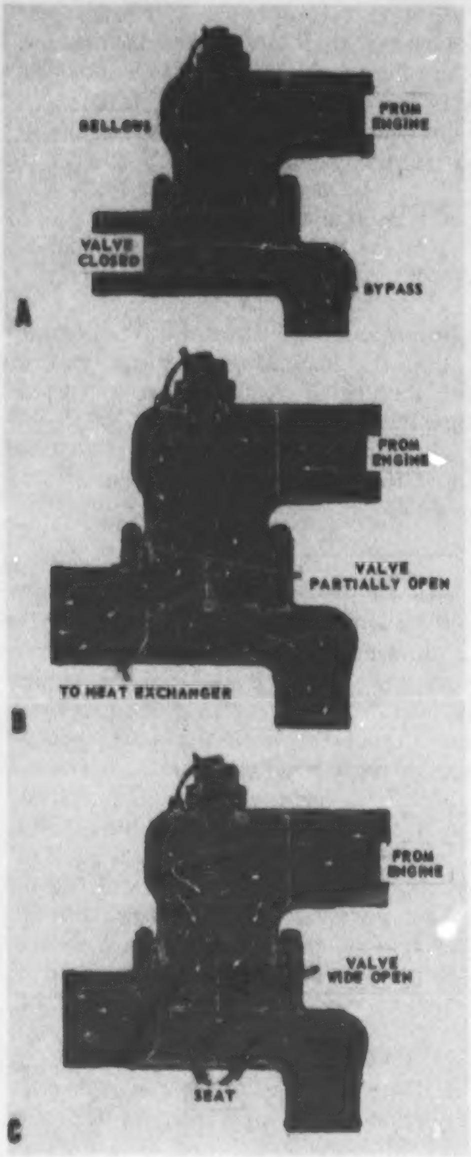

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Figure 8-20.—Operation of a conventional thermostatic valve.

engines is shown in figure 8-21. Even though regulators of the type shown are automatic or self-operated, provisions are included in most installations for manual operation in the event that the automatic feature fails.

The temperature regulator consists of a valve and a thermostatic control unit mounted on the valve. The thermostatic control unit consists of two parts: the temperature-control element and the control assembly.

The temperature-control element consists of a bellows connected by a flexible armored tube to a bulb mounted in the engine cooling-water discharge line. The temperature-control element is essentially two sealed chambers. One chamber is formed by the bellows and cap which are sealed together at the bottom; the other chamber is in the bulb. The entire system (except for a small space at the top of the bulb) is filled with a mixture of ether and alcohol which vaporizes at a low temperature. When the bulb is heated, the liquid vaporizes and the pressure within the bulb increases. This forces the liquid out of the bulb and through the tube; the bellows is moved down and operates the valve.

The control assembly consists of a spring-loaded mechanical linkage which connects the temperature-control element to the valve stem. The coil spring in the control assembly provides the force necessary to balance the force of the vapor pressure in the temperature-control element.

Thus, the downward force of the temperature-control element is balanced, at any point, by the upward force of the spring which permits the valve to be set to hold the temperature of the engine cooling water within the allowed limits.

The regulator operates only within the temperature range marked on the nameplate; it may be adjusted for any temperature within this range. The setting is controlled by the range-adjusting wheel, located under the spring seat. A pointer attached to the spring seat indicates the temperature setting on a scale which is attached to the regulator frame. The scale is graduated from 0 to 9, representing the total operating range of the regulator. (See fig. 8-22.)

The location of a temperature regulator in one type of installation is shown in figure 8-15;

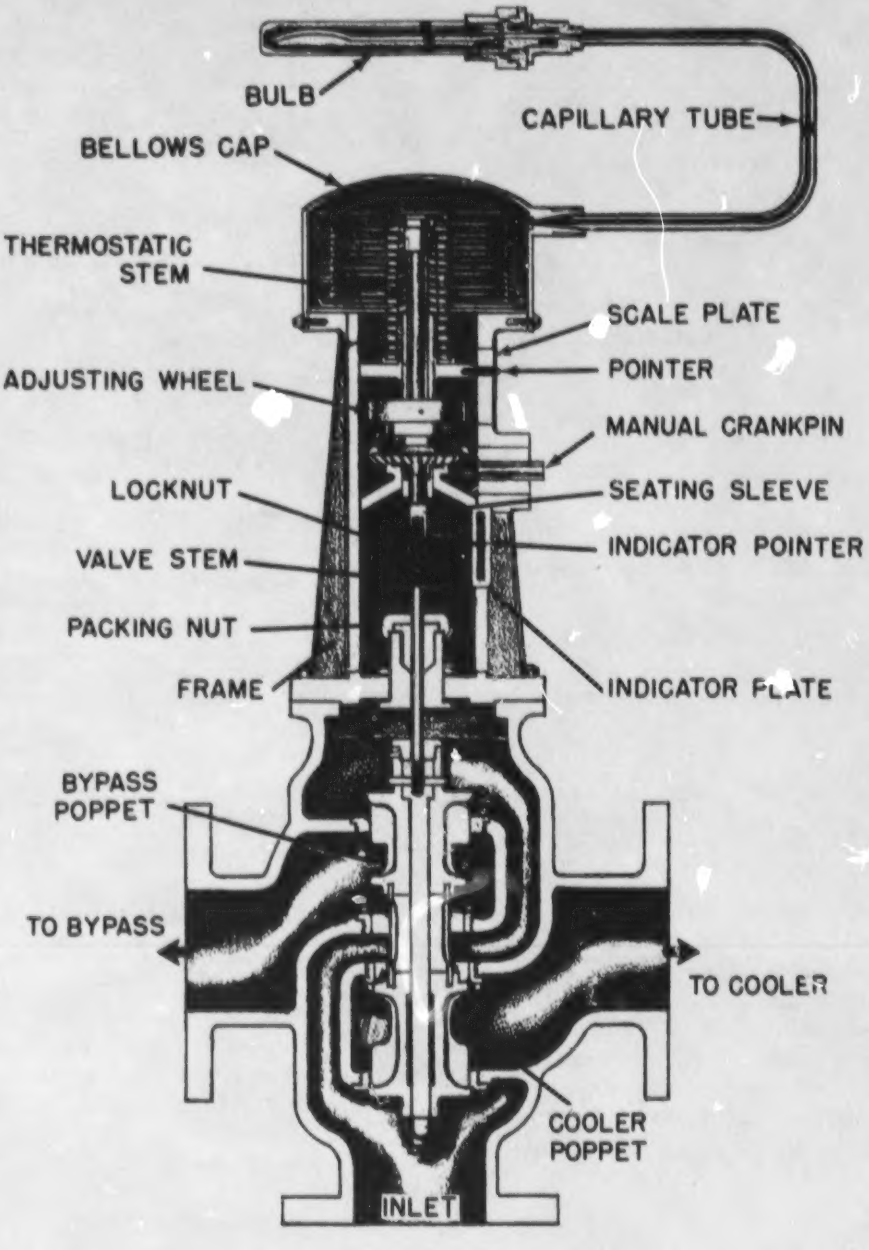
BULB
CAPILLARY TUBE
BELLOWS CAP
THERMOSTATIC STEM
SCALE PLATE
POINTER
ADJUSTING WHEEL
MANUAL CRANKPIN
LOCKNUT
SEATING SLEEVE
INDICATOR POINTER
VALVE STEM
PACKING NUT
FRAME
INDICATOR PLATE
BYPASS POPPET
TO BYPASS
TO COOLER
COOLER POPPET
INLET

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Figure 8-21.—Automatic temperature regulator.

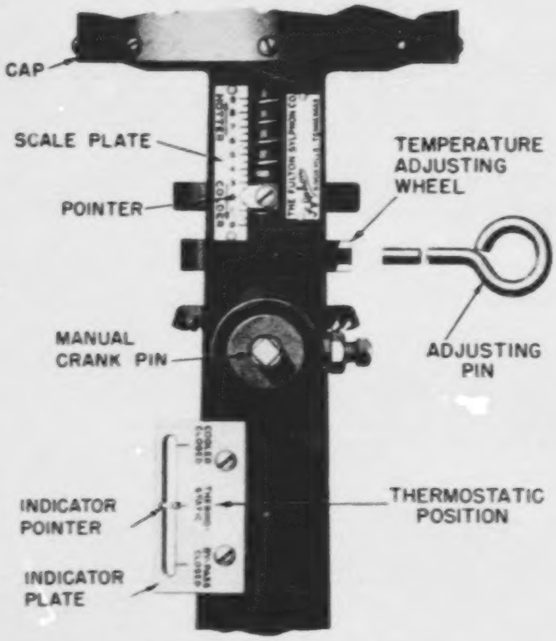

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Figure 8-22.—Scale and indicator plates of temperature regulator.

note that the regulator is located in the seawater circuit. In most engines, the regulator is located in the freshwater circuit.

When located in the seawater circuit, the regulator controls the amount of seawater flowing through the coolers. When the temperature of the freshwater becomes greater than the temperature for which the regulator is set, the regulator actuates a valve to increase the flow of seawater through the coolers. When the freshwater temperature is below the temperature for which the regulator is set, the regulator actuates a valve to decrease the flow of seawater through the coolers.

In installations where the regulator is in the freshwater circuit, water is directed to the cooler when the temperature of the water is above the maximum setting of the regulator. After passing through the cooler where the temperature of the water is decreased, the water returns to the suction side of the freshwater pump to be recirculated. When the temperature of the water is below the maximum setting of the regulator, the water bypasses the cooler and flows directly to the suction side of the pump. Bypassing the cooler permits the water to be recirculated through the engine; in this way, the temperature of the water is raised to the proper operating level.

Regardless of whether the regulator is in the fresh or seawater circuit, the bulb which causes the regulator to operate is located in the freshwater discharge line of the engine.

Temperature regulators are used not only to control the temperature of the freshwater but also to control indirectly the temperature of the oil discharge from the lubricating oil cooler. Control of lubricating oil temperature is possible because the water (freshwater or saltwater) that is passed through the regulator and the freshwater cooler is the cooling agent in the lubricating oil cooler. When the lubricating oil is cooled by seawater, two temperature regulators are installed in the seawater circuit. The temperature regulator bulb of the regulator that controls the temperature of the freshwater is installed in the freshwater circuit; the bulb of the regulator that controls lubricating oil temperature is installed in the lubricating oil system.

MAINTENANCE OF ENGINE COOLING SYSTEMS

Since the purpose of an engine cooling system is to keep engine parts and working fluids at safe operating temperatures, steps must be taken to prevent corrosion and to reduce the tendency toward scale formation in cooling systems. Heat exchangers and water jackets must be properly cleaned or repaired whenever a planned maintenance action of faulty operation reveals that it is necessary; circulating pumps must be maintained in the best of operating conditions. The information in this section deals with the maintenance of heat exchangers and the reduction of scale formation by freshwater treatment. You will find information on the care of pumps in chapter 15 of this manual.

CARE OF HEAT EXCHANGERS

If a cooler is to effectively remove the excess heat from lubricating oil or freshwater, it is essential that the cooler be inspected periodically (usually at 30-60 day intervals) for excessive scale and foreign material. Excessive scale and accumulations of dirt reduce the efficiency of the cooler. Unless the cooler is properly cleaned, therefore, scale and dirt may accumulate on the tubes to such an extent that the cooler cannot remove enough heat to keep the cooled liquid within prescribed limits.

The accumulation of scale and dirt on the saltwater side of a cooler element is usually a gradual process. The presence of scale and dirt on the cooler tubes is usually indicated, depending on the use of the cooler, by a gradual increase in oil temperature or in freshwater temperature. Excessive accumulations on the tubes and clogging of the tubes are both indicated by a gradual increase in the difference between the inlet and outlet pressures of the cooler. As the amount of scale increases, the quantity of seawater that must be circulated to obtain the same cooling effect will increase due to the insulating effect of the scale coating that forms on the saltwater side of the cooler. When scale formation is suspected, the heat exchanger element should be removed, inspected, and cleaned.

Scale will form on the saltwater side of a cooler during normal operation because of the dissolved salts present in the water. One of the factors which tends to increase the rate of formation of scale is operating the engine with a high seawater temperature. The seawater discharge temperature should be maintained below 130°F. At higher temperatures the amount of scale formation is considerably greater.

Cooler elements may become clogged with such materials as marine life, grease, or sand. Such clogging greatly reduces cooler capacity. Cooler elements may also become clogged through faulty operation of the seawater strainer, improper lubrication of pumps, or, in oil coolers, a leaky element.

Seawater strainers are provided to prevent the entrance of seaweed and other debris into the circulating system. These strainers must be replaced or repaired when the screens become punctured or otherwise incapable of preventing entry of dirt into the system. Remember that when a seawater strainer has to be cleaned or replaced, the sea suction valve must be secured before the strainer is opened to prevent flooding the space. This precaution must be taken whenever work is to be done on any saltwater piping connected directly to the sea.

Many seawater pumps are provided with grease cups for bearing lubrication. Turning such grease cups down too often may cause the grease to be squeezed into the water being pumped. The grease will be carried into the cooler element and deposited there. The film of grease thus deposited will greatly reduce the capacity of the cooler. Seawater pumps should be lubricated as specified in the Planned Maintenance System.

A hole in the element of the oil cooler will allow the passage of lube oil into the water which is used for coil cooling. Some of the oil introduced into the water may be deposited on the water side of the cooler elements. The film of oil so deposited will act in the same manner as the grease film just discussed.

Leaks in oil coolers should be repaired as soon as possible. A vigilant lookout should be maintained for signs of oil or grease in the freshwater system. If oil or grease is present, locate and eliminate the source of the contamination.

When there are symptoms which indicate that excessive amounts of scale or accumulation of dirt are forming on the saltwater side of a cooler, remove and clean the element. For ordinary cleaning of a cooler element (shell-and-tube type), use an air lance to remove foreign debris from the water side. For more severe fouling, use a water lance instead of an air lance. Where there is extreme fouling due to oil or foreign material, run a rotating-bristle brush through each tube or drive soft rubber plugs (if available) through the tubes with an air or water gun. Then use a water lance to remove any remaining foreign material from the tubes.

You must be careful not to use abrasive tools capable of scratching or marring the tube surfaces. Never use wire brushes or metal scrapers. Carefully use air and water lances and other cleaning equipment and procedures to avoid damaging the element. The cleaning of a cooler element will be much more effective and more easily accomplished if the cleaning is done before the accumulations on the surfaces of the element have had time to dry and harden.

Clean the oil sides of shell-and-tube coolers of the removable tube-bundle type by removing the tube bundle and washing it with a jet of hot freshwater. Be sure that you dry the tube bundle thoroughly prior to reassembly. Note, however, that with proper attention to purification and filtering of the oil, cleaning of the oil side of this type of cooler should seldom be necessary.

A chemical rather than a mechanical method is required for cleaning strut-tube type coolers. Clean the oil side first; otherwise, some of the oil will wash out of the tubes and nullify any cleaning already accomplished.

The items of equipment you will need to clean the oil side of a cooler will vary in size, depending on the size of the unit. With an arrangement such as illustrated in figure 8-23, an approved cleaning agent is pumped through the cooler. You can speed up the cleaning process considerably by circulating the cleaning agent in a direction opposite to the normal oil flow. Check the progress of the cleaning process frequently. The process is complete when the solution flows freely through the cooler.

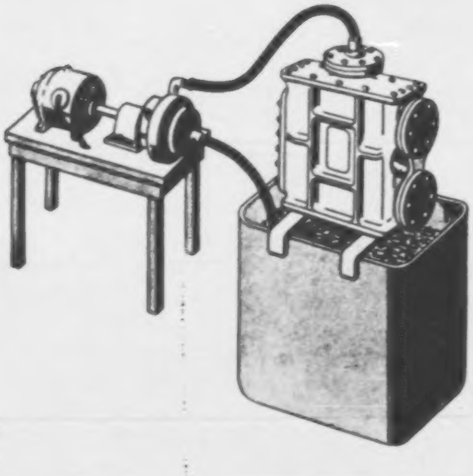

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Figure 8-23.—Equipment for cleaning a heat exchanger.

You may use a hand pump to clean small coolers. Submerge the element in a container of cleaning solution and then use the pump to force the solution through the element.

Clean the oil side of a cooler in the open or in a well-ventilated space if the cleaning agents give off toxic vapors.

Clean the water side of oil coolers chemically by submerging the unit in a weak solution of muriatic acid. (The solution should be 1 part muriatic acid to 9 parts cold water; to this is added, for every gallon of muriatic acid, 2 pounds of oxalic acid and 1/4 ounce of pyridine.) The tank containing the acid must be of earthenware or other acid-resistant material. Two additional tanks are necessary to complete the cleaning process. Fill the second tank with cold freshwater and fill the third with a 5% solution of sodium carbonate.

To facilitate access to the parts of a cooler, disassemble the unit; remove the core from the case if practicable. Support the unit to be cleaned with a wire and submerge it in the acid solution. Foaming will occur and continue as long as the cleansing action is taking place. When foaming ceases, place the unit in the tank of cold water for approximately 1 minute. Then, immerse the unit in the solution of sodium carbonate. Bubbling will occur if all the acid was not removed from the unit by the freshwater. When bubbling occurs, leave the unit in the solution of sodium carbonate until the bubbling ceases. Then, remove the unit from the solution and flush it with freshwater. Warm water should be used, if available. This cleaning procedure can be used to remove any deposits from the cooler case and covers.

Corrosion or erosion of the element in a heat exchanger or operation at excessive pressure may cause LEAKS. These leaks can develop either in the element or in the casing. You can usually detect leakage from the cooler casing by visual inspection. Element leaks, however, are more difficult to detect. Any noticeable decline or rise in the freshwater tank level, with the temperature remaining normal, usually indicates leakage. A leak in the tubes of an oil cooler may be evidenced by water in the lube oil or by slicks in the cooling water. Other indications are the apparent increase in the volume of lube oil in the engine sumps or the loss of oil from the sump without other apparent causes of leakage.

A hole made by corrosion in a cooler element indicates that corrosion probably exists throughout the element, and you should make a thorough inspection. Corrosion can be prevented to a large extent by using the prescribed freshwater treatment, inspecting and replacing zincs as necessary, and venting the cooler to remove entrapped air.

Holes resulting from erosion are generally caused by particles of grit (sand, dirt, etc which usually result from operation in shallow water) striking the element at high velocity. For the most part, such grit is so fine that it will pass through the seawater strainer. If the strainer is defective, even the larger particles of grit may enter the cooler.

Erosion by water at high velocity may also cause holes in a cooler element. Sometimes water flow has to be increased above rated capacity to maintain the desired freshwater temperature. Whenever it is necessary to greatly increase water flow, the cooler should be cleaned.

If the maximum operating pressure (indicated on the exchanger nameplate) is exceeded, leaks are apt to result. Excessive pressure is likely to occur whenever there is clogging because of the added pressure needed to force a given quantity of water through the restricted element. If there is any reason to suspect that there are leaks in the heat exchanger element, the best method of locating them is to apply a hydrostatic test. Conduct the test as follows:

1. Remove the element from the casing.
2. Block off the discharge side of the element.
3. Attach a pressure gage to the inlet line of the element.
4. Supply low-pressure air to the inlet side of the element. Air pressure must not exceed design pressure for the element.
5. Immerse the element in a tank of water.
6. Check for bubbles.

A similar test can be made by filling the element with water under pressure; then watch for bubbles.

FRESHWATER TREATMENT AND TESTS

The purity of the water used in the closed circuit of an engine cooling system must be maintained at a high level to prevent the formation of scale and to control corrosion within the cooling system. To prevent these undesirable conditions, fill the cooling system with distilled water with zero hardness and treat the water so that the alkalinity and the sodium chromate and chloride concentrations are maintained within specified limits. The information in this section deals with the treatment of water used in the closed circuit of an engine cooling system and with the tests used to determine the effectiveness of the treatment.

Need for Freshwater Treatment

All water contains some impurities. Impurities dissolved or suspended in the water of an engine cooling system can cause trouble in the system by forming scale and causing corrosion. Generally, scale forms only on the hot surfaces in the internal passages of the engine cooling system, and not throughout the system.

The formation of scale within the cooling system of an engine is caused primarily by certain sulphates of magnesium and calcium. Since these sulphates are present in seawater and since cooling water for shipboard engines is generally distilled from seawater, some slight contamination of the cooling water must always be expected. However, distilled water placed in the cooling system of an engine simplifies the control of the scale-forming salts.

SCALE PREVENTION.–Steps must be taken to prevent the formation of scale because scale is a very poor conductor of heat. If it is allowed to accumulate in the cooling system of an engine, scale will prevent the proper transfer of heat from the hot engine parts to the cooling water. Improper heat transfer, particularly uneven heat transfer, creates stresses in the affected parts; these stresses may cause cylinder liners, heads, and other parts of the engine to crack. If the water in the cooling system of an engine is properly treated, scale formation will be prevented and casualties caused by improper heat transfer will be less likely.

Unless the water used in the cooling system is properly treated, the internal surfaces of the cooling system may become pitted or eaten away by corrosion. Such corrosion generally results from acidity of the water and oxygen dissolved in the water.

CORROSION CONTROL.–Corrosion in the cooling system of an engine may lead to cracks in liners and heads and may cause serious damage to other parts of the cooling system. Corrosion in an engine cooling system can be controlled with proper water treatment. The chemicals used for treating freshwater in engine cooling systems help to prevent scale and corrosion by maintaining the (1) alkalinity, (2) chloride content, and (3) chromate concentration of the water within specified limits.

Terms and Units Related to Water Tests

The condition of the treated water is described in various terms and units. These standard terms and units are used in recording information regarding the tests and in making reports.

The term used to identify the alkalinity of the treated cooling water is "pH." The pH unit does not measure alkalinity directly; however, it is related to alkalinity in such a way that a pH number gives an indication of the alkalinity or acidity of the cooling water. The pH scale of numbers ranges from 0 to 14. On this scale, pH 7 is the neutral point. Solutions having a pH value above 7 (as pH 8, pH 10, etc) are defined as being alkaline solutions; solutions having pH values below 7 are defined as being acid solutions.

The concentrations of chromate and chloride in a test sample of treated water are indicated in terms of parts per million (ppm). Parts per million is a weight-per-weight unit denoting the number of parts of a specified substance in a million parts of water. For example, 58.5 pounds of salt in 1,000,000 pounds of water represent a concentration of 58.5 ppm. Note, also, that 58.5 ounces of salt dissolved in 1,000,000 ounces of water, or 58.5 tons of salt dissolved in 1,000,000 tons of water, represent the same concentration–that is, 58.5 ppm.

Chromate, pH, and Chloride Limits

To minimize serious corrosion and scale deposits and to prolong the life of the cooling system, the treated water must be maintained within specified limits.

The chromate concentration must be maintained between the limits of 700 to 1700 ppm. A minimum concentration is specified because lower concentrations can result in accelerated corrosion. A maximum concentration is specified to eliminate waste.

The pH value must be maintained within the range of 8.25 and 9.75. A minimum value is specified because lower values can result in accelerated corrosion. To avoid corrosion which occurs in highly alkaline waters, the alkalinity should not be allowed to exceed a 9.75 value.

The chloride content must be kept to the lowest value practicable and must never exceed 100 ppm.

Water Treatment

The treatment of water in an engine cooling system requires the use of chemicals to maintain the alkalinity and chromate concentration of the water at specified levels. If the alkalinity and chromate concentration are properly maintained, scale formation and corrosive action will be greatly reduced. Remember, however, that the water treatment discussed in this chapter is a preventive treatment only; it will not remove scale which has already formed in the cooling system.

Before initiating the water treatment, be sure the cooling system of the engine has been thoroughly cleaned, using the method outlined in chapter 233 (9412), *Naval Ships' Technical Manual.* After cleaning, thoroughly flush the system with freshwater and fill it with distilled water.

If available instructions do not indicate the proper chemical dosage for a specific engine, you must determine the capacity of the complete cooling system (in gallons of water) before you can determine the proper dosage of chemicals.

Two different combinations of chemicals are authorized for use in the Navy for treating water in engine cooling systems. Therefore, the treatment you will use for any particular engine will depend on which set of chemicals is available. The two combinations of chemicals are: (1) a combination of sodium dichromate and Navy boiler compound and (2) a combination of sodium chromate and disodium phosphate.

SODIUM DICHROMATE AND BOILER COMPOUND TREATMENT.–For each 100 gallons of cooling water to be treated, add 1.5 pounds of sodium dichromate and 3 pounds of boiler compound and dissolve in approximately 1.5 gallons of warm distilled water. This solution is usually added to the cooling system at the expansion tank. Circulate the solution through the system for at least 10 minutes. Then draw off a 1/2-pint sample of the treated water, allow it to cool to at least 80°F, and test it to determine the chromate, alkalinity, and chloride concentration. The procedures for conducting the required tests, using the test kit provided for this purpose, are discussed later in this chapter under the heading of "Water Tests."

After initial treatment, you must test the cooling water after each day of operation. When it becomes apparent that the concentration of chromate and alkalinity will not drop below the prescribed minimum, you may increase the interval between tests to the maximum of once a month as prescribed by the Planned Maintenance System.

If tests reveal that the chromate concentration drops below 700 ppm, add a solution containing one pound of sodium dichromate and two pounds of boiler compound for each 100 gallons of cooling water. The addition will bring the chromate concentration within the specified range. If the alkalinity is too high, omit the boiler compound in the solution. The addition of sodium dichromate alone will reduce the alkalinity.

To correct a low pH value, add a solution containing 1.5 pounds of boiler compound for each 100 gallons of cooling water. This addition should bring the pH value within the specified range. If tests reveal that alkalinity is high and chromate concentration is low, add sodium dichromate alone before adjusting the alkalinity. If the alkalinity is too high and the chromate concentration is within the specified range, drain 25% of the cooling water from the system and refill with freshwater. Circulate the coolant through the system, retest, and treat as necessary.

The concentration of chlorides in the cooling water must NEVER be allowed to exceed 100 ppm. If the test indicates that this limit is exceeded, the entire system must be drained and the source of chloride contamination must be located and remedied. Then, flush the system, refill with freshwater, and chemically treat to the proper limits.

SODIUM CHROMATE AND DISODIUM PHOSPHATE TREATMENT.–When using sodium chromate and disodium phosphate for cooling water treatment, follow the same procedures for preparing the system, mixing the solution, testing and controlling the chromate concentration and alkalinity that you used for sodium dichromate and boiler compound

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treatment. The only differences between the two treatments are (1) the chemicals used and (2) the amounts used.

To initiate the water treatment using sodium chromate and disodium phosphate: for each 100 gallons of cooling water to be treated, mix a solution consisting of 1.5 pounds of sodium and 1.5 pounds of disodium phosphate compound dissolved in approximately 1.5 gallons of hot distilled water. Add this solution to the cooling system, circulate in the system, and conduct tests.

If tests reveal that the chromate concentration is below 700 ppm, a solution containing 1 pound of sodium chromate and 1 pound of disodium phosphate should be added for each 100 gallons of cooling water. The addition will bring the chromate concentration and pH value within the specified range.

If tests reveal that the pH value is low (below 8.25), add a solution containing 1 pound of disodium phosphate for each 100 gallons of cooling water. This addition should bring the pH value above the specified minimum. If the pH value is found to be too high (above 9.75), drain 25% of the cooling water from the system and refill with freshwater. Circulate the coolant through the system, retest, and treat as necessary.

If tests reveal that chloride concentration exceeds the prescribed limits (above 100 ppm) drain the entire system, locate the source of chloride contamination, and remedy the trouble. Then, flush the system, refill with freshwater, and chemically treat to the proper limits.

Conducting Tests

The test kit provided for testing engine cooling water is specifically designed to enable shipboard personnel to conduct chromate, alkalinity (pH), and chloride tests quickly and easily. The kit contains all the equipment and chemicals necessary to perform the required tests.

The tests for chromate and alkalinity by color comparison in which the color of the test sample is compared with the color of two glass disks representing the specified maximum and minimum limits. The chloride test is of a different type; the chloride concentration is determined by noting the color and condition of the sample after the addition of a chloride test tablet.

Before taking a test sample of the cooling water, drain water from the drain cock for several seconds. Then draw off a 1/2-pint sample. Allow it to cool to at least 80°F before testing. If suspended material is noticed in the sample, filter the water to keep the suspended material from interfering with the colorimetric tests.

To filter the sample, fold a circular filter paper to form a cone. Place the cone in the funnel which is provided. Wet the cone with distilled water and press the upper edge of the cone to the funnel. Place the funnel in the cylindrical sample bottle or other clear, suitable container. Carefully pour the sample water into the cone.

When performing chromate and pH tests, use either natural daylight or a daylight fluorescent lamp as a light source. Do not use incandescent lighting, as the results obtained will be erroneous. When you make tests in natural daylight, hold the comparator up to the brightest part of the sky, but about 30° from the sun. Avoid strong light on the observer's side of the comparator, as reflections will interfere with the necessary comparisons. If possible, the observer and comparator should be in a shadow.

To conduct the test to determine the chromate concentration, proceed as follows:

1. Fill the test tube with cooling water sample and place in the center position of the comparator.
2. Hold the comparator to a suitable light source.
3. If the color of the sample is between the colors of the disks marked 700 and 1700, the chromate concentration is satisfactory. Be careful to note the color rather than the intensity of color. Do not compare the darkness or lightness of the colors, rather, determine whether the sample is yellower or bluer than the color disk standards.

4. If the color is bluer (bluish-green) than the color disk marked 700, the chromate content is too low.
5. If the color is yellower (yellowish-green) than the color disk marked 1700, the chromate content is high. High chromate content is not harmful but is wasteful.

To conduct the test to determine the pH (alkalinity) value, proceed as follows:

1. Fill three test tubes to the prescribed mark with cooling water sample.
2. Add 15 drops of pH indicator to one test tube, shake, and place in center position in comparator. Place the other two test tubes in the remaining positions in the comparator.
3. Hold comparator to a suitable light source.
4. If the color of the sample is between the colors on the color disks marked 8.25 and 9.75, pH is satisfactory.
5. If the color is yellower (yellowish-green) than the color disk marked 8.25, the pH value is low.
6. If the color is bluer (bluish-green) than the color disk marked 9.75, the pH is high.

To test for chloride concentration, it is necessary that the sample to be tested contains chromate and is alkaline. The chloride test, therefore, should be run after the chromate and alkalinity have been determined (and corrected if necessary) to ensure the proper conditions. Should it be necessary to perform the chloride test before adjusting the chromate content and alkalinity, the sample must have the characteristic yellow color of chromate.

To conduct the test to determine the chloride content proceed as follows:

1. Fill the cylindrical sample bottle to the 50-milliliter mark with cooling water sample.
2. Add one chloride test tablet, insert a stopper in the bottle, and shake until tablet is completely dissolved.
3. If the sample develops a reddish-brown color, the chloride content is below the safe maximum limit.
4. If the sample becomes a cloudy yellow-green, the chloride content is high.

Ships that are not equipped to conduct the required tests for chromate, alkalinity (pH), and chloride concentration in engine cooling water may submit samples of cooling water to the nearest naval shipyard, tender, or advanced base laboratory for analysis. Where test facilities are not available, the cooling system must be drained, flushed, refilled, and chemically treated at intervals of not more than 3 weeks.

SAFETY PRECAUTIONS

Diesel-driven ships built in recent years have (installed aboard) a new type distilling plant that uses diesel engine jacket water for a heat source. Although the jacket water does not come in direct contact with the distilled water, the chance of a leak is still present. Since chromate chemicals are considered health hazards, they are NOT to be used in engines that supply jacket water as a heat source to evaporators. In such installations, soluble oil inhibitors are used instead of chromate chemicals. If you encounter such a system and do not have a soluble oil inhibitor specification for your installation, contact NAVSEC for instructions.

The chromate chemicals used in water treatment of cooling systems are classified as a health hazard. Personnel should avoid any contact of skin or eyes with chromates in either a solid form or a solution. Also, avoid breathing chromate dust or solution spray. Personnel involved in handling chromate chemicals should use available protective equipment. The protective equipment to be used, such as goggles, face shields, rubber gloves, aprons, and dust respirators should be consistent with the type and degree of hazard involved. When the skin has come in contact with chromates, the affected areas should be washed with plenty of soap and water immediately after exposure.

Suitable precautions must be taken to prevent contamination of the ship's potable freshwater system. Backflow of the engine cooling water through the filling connection must be prevented. Specifications require that an air gap remain between the freshwater supply and fill connection. This arrangement must NOT be altered.

When the engine cooling system must be protected from freezing, glycol base antifreeze is used. The antifreeze solutions specified by the Navy contain their own inhibitors which adequately protect the cooling system from corrosion. Therefore, no additional inhibitors are required.

Whenever it is necessary to change from one type of water treatment to the other, completely drain and flush the system free of any chromates or glycol base antifreeze to prevent any mixing of these materials.

CHAPTER 9

ENGINE LUBRICATING OIL SYSTEMS

Lubrication is as important to successful engine operation as air, fuel, and heat are to combustion. Lubrication is frequently considered one of the most important factors in efficient engine operation. It is important not only that the proper type of lubricant be used, but also that the lubricant be supplied to the engine parts in the proper quantities at the proper temperature and that provisions be made to remove any impurities which enter the system.

For proper operation of an engine the contacting surfaces of all moving parts of the engine must be kept free from abrasion and there must be a minimum of friction and wear. Sliding contact between two dry metal surfaces under pressure causes excessive friction, heat, and wear. Friction, heat, and wear can be greatly reduced if metal-to-metal contact is prevented by a clean film of lubricant between the metal surfaces. The necessary film between the bearing surfaces in naval machinery is provided by either a specified oil or grease.

FUNCTIONS OF OIL

A lubricating oil with the necessary properties and characteristics will: (1) provide a film of proper thickness between the bearing surfaces, under all conditions of operation; (2) remain stable under changing temperature conditions; and (3) not corrode the metal surfaces. If the lubricating oil is to meet these requirements, the engine temperature during operation must NOT exceed a specified limit.

In addition to preventing metal-to-metal contact, the lubricating oil must also (1) form a seal between the piston rings and the cylinder wall, (2) aid in engine cooling, and (3) aid in keeping the inside of the engine free of sludge.

PROTECTIVE FILM

A direct metal-to-metal moving contact is similar to a filing action. The filing action is due to minute irregularities in the surfaces. The severity of the filing action depends on the finish of the surfaces, the force with which the surfaces are brought into contact, and the relative hardness of the materials used. Lubricating oil fills the minute cavities in bearing surfaces and forms a film between the sliding surfaces to prevent high friction losses and rapid wear of engine parts. The lack of a proper oil film will result in a seized (frozen) piston, wiped bearings, and stuck piston rings.

COOLING

Lubricating oil assists in cooling the engine by transferring or carrying away heat from localized "hot" spots in the engine. The principal parts from which oil absorbs heat are the bearings, the journal surfaces, and the pistons. In some engines, the oil carries the heat to the sump where the heat dissipates in the mass of oil. However, most modern internal-combustion engines use a centralized pressure-feed lubrication system. This type of system has an oil cooler or heat exchanger where the heat from the oil is transferred to the circulating water of the cooling system.

SLUDGE CONTROL

Almost any type of gummy or carbonaceous material which accumulates in lubricating oil is called sludge. Most engine lubricating oils have some natural ability for preventing conditions which may cause sludge to form and for carrying sludge that does form in a finely suspended state until it is removed by filtering equipment. Chemicals are added to some oils to improve their ability to prevent and to remove sludge.

The formation of sludge is greatly reduced when the lubricating oil has the proper stability. Stability is defined as the oil's ability to resist oxidation and deterioration for long periods. Proper stability is essential for maintaining a strong oil film, or body of oil, at varying temperature conditions. Such a film will ensure sufficient oiliness, or film strength, between the piston and the cylinder wall so that partly burned fuel and the exhaust gases cannot get by the piston rings to form sludge.

Various factors may tend to cause sludge to form in an engine. Carbon from the combustion chambers or from the evaporation of oil on a hot surface, such as the underside of a piston, will cause sludge to form. Gummy, partially burned fuel, which gets past the piston rings, or an emulsion of lubricating oil and water, which may enter the lubricating oil system, will also tend to cause sludge.

Sludge in the lubricating oil system of an engine is harmful for several reasons. In addition to carbon and gummy material, sludge may contain abrasive ingredients, such as dust from the atmosphere; rust as a result of water condensation in the engine; and metallic particles resulting from wear of engine parts, Sludge in engine lubricating oil causes premature wear of parts and eventual breakdown of the engine. Sludge may clog the oil pump screen or collect at the end of the oil passage leading to a bearing and prevent sufficient oil from reaching the parts to be lubricated. Sludge will coat the inside of the crankcase, act as insulation, blanket the heat inside the engine, raise the oil temperature, and induce oxidation. Sludge will accumulate on the underside of the pistons and prevent proper heat transfer, thereby raising piston temperatures. Sludge in lubricating oil also contributes to piston ring sticking.

CHARACTERISTICS AND TESTS OF OIL

Lubricants obtained by the Navy are tested for such characteristics as viscosity, pour point, flashpoint, fire point, autogenous ignition point, neutralization number, demulsibility, and precipitation number. The lubricants must meet the following requirements:

1. They must have a suitable viscosity at the operating temperature of the bearing being lubricated.
2. They must form durable boundary films on the metal rubbing surfaces.
3. They must not chemically attack the journal or the bearing metals.
4. They must not change chemical composition with use.

VISCOSITY

The tendency of a liquid to resist flow or change of shape is known as viscosity. A liquid of high viscosity flows very slowly. The viscosity of oil varies with an increase or a decrease in temperature. Viscosity decreases when the temperature is increased, and increases when the temperature is decreased. (On a cold morning, it is difficult to turn over an engine because of the high viscosity, or stiffness, of the lube oil.)

Viscosity at operating temperatures should be high enough for the oil to maintain a fluid film regardless of the load imposed upon it. However, the viscosity should not be so high that it causes drag or excessive fluid friction, which in turn reduces engine efficiency and results in high bearing temperatures. The viscosity at operating temperatures determines the fluid friction, the heat generated in the bearing, and the rate of flow of the oil under given conditions. Therefore, you must know the viscosity of oils at operating temperatures to select the proper oil for a specific purpose.

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Determining the Viscosity

The measure of the viscosity of an oil is the number of seconds required for a specified quantity (60 cc) at a specified temperature to flow through a standard orifice. When the viscosity of an oil is measured, the result is reported in a three-unit term containing (1) the number of seconds required for the sample of oil to pass through the orifice, (2) the type of viscosimeter used (this indicates the orifice size), and (3) the temperature of the oil tested. Navy fuel oil is generally tested in a Saybolt Furol viscosimeter (illustrated in fig. 9-1), and lubricating oil is generally tested in a Saybolt Universal viscosimeter. Thus, the viscosity of a fuel oil might be expressed as "20 seconds, Saybolt Furol (SSF), at 122° F" (standard temperature used for testing fuel oil). The viscosity of a lubricating oil might be expressed as "190 seconds, Saybolt Universal (SSU), at 130° F." For testing a lubricating oil, 130° F or 210° F is used as standard temperature, depending upon the symbol of the individual oil. You can find the correct temperature to be used for each specific symbol of lubricating oil in chapter 262 (9450) *Naval Ships' Technical Manual.*

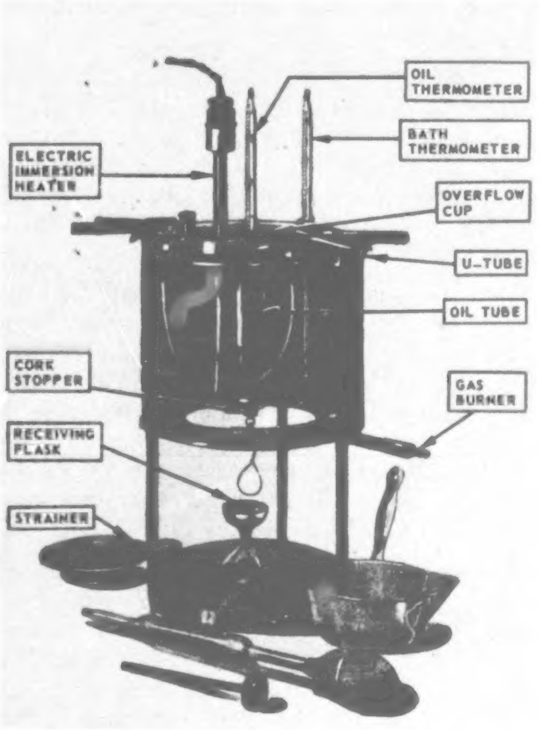

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Figure 9-1.—Saybolt Furol Viscosimeter.

The only difference between the Saybolt Furol viscosimeter and the Saybolt Universal viscosimeter is the size of the discharge orifice. About one-tenth the time is required for a specific quantity of oil at a given viscosity to flow through the orifice of a Saybolt Furol instrument as through the orifice of a Saybolt Universal viscosimeter.

Since temperature is an important factor in determining viscosity, you must watch the thermometer readings carefully. The Saybolt Furol viscosimeter has two thermometers: one to record the temperature of the outer bath vessel, the other to check the temperature of the oil being tested.

As an EN, you should be familiar with the recommended procedure for checking the viscosity of a lube oil. We cannot overemphasize the importance of using lube oil of the correct viscosity. When making an oil change, you can easily ensure that the right oil is used. However, the viscosity of the lube oil in an engine changes while the engine is running; the change is usually toward a lower viscosity because of DILUTION with fuel oil.

A simple device for checking dilution is the VISGAGE, shown in figure 9-2. (The master tube is filled and sealed at the factory; you should NOT tamper with this instrument.) The visgage consists of two glass tubes attached to a scale calibrated in Seconds, Saybolt Universal (SSU) at 100° F. The MASTER TUBE (upper tube) contains a small steel ball immersed in oil which has a viscosity of 200 SSU at 100° F (standard for testing other oils).

The TRIAL TUBE is similar to the master tube but has a plunger for drawing a sample of oil into the tube for testing. The steel ball in the trial tube is identical with the one in the master tube.

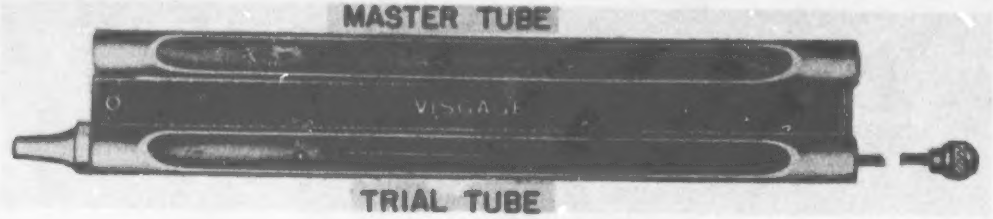

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Figure 9-2.—The visgage.

Before studying the operation of the visgage, notice the two scales between the tubes (fig. 9-2). Both scales are used to read the viscosity of sample oils drawn into the trial tube. Scale A, adjacent to the master tube, is calibrated from zero at the right to 200 at the left, and scale B, adjacent to the trial tube, from 200 at the left to 2,000 at the right.

When using a visgage, put a small sample of oil in a clean container. Insert the nozzle of the trial tube into the oil and draw the plunger all the way up, filling the trial tube with oil. Then tilt the left end of the instrument down at about a 30° angle, so that the two steel balls roll down through the two oils. Be careful to keep the sample oil from coming out of the nozzle.

If the viscosities of the sample and the standard oil differ, the two steel balls will move downward at different speeds in the tubes. As the leading ball approaches the 200 line at the left end of the scale, gradually tilt the left end of the visgage upward. Tilting will slow the movement of the steel balls.

At the instant the leading ball reaches the 200 line, bring the visgage back to level and, at the same time, read the position of the lagging or slower moving ball on the nearest scale. That reading will be the viscosity of the sample oil, in SSU at 100° F.

If the ball in the upper tube travels faster, read the position, on scale B, of the ball in the trial tube at the moment the upper ball reaches the 200 line. That reading will be the viscosity of the sample oil at 100° F (for example, 275 SSU).

If the lower ball (in the sample oil) travels faster, read the position, on scale A, of the ball in the master tube, at the moment the lower ball reaches the 200 line. That reading (for example, 125 SSU) is the viscosity of the sample oil at 100° F.

If the two balls move at the same speed and reach the left end of the visgage together, the viscosity of the sample oil is the same as that of the standard oil.

Remember that the temperature of both the sample oil and the standard oil should be approximately 100° F. By holding the gage for a few minutes in the palms of your hands, you can adjust the temperature of the oils by warming the oils to body temperature (98.6° F), which approximates 100° F.

Merely determining the viscosity of the sample lube oil does not solve the question of whether the lube oil has become diluted to such an extent that it should no longer be used. After using the visgage to determine the viscosities of both the new and the old oils, you should then turn to a DILUTION CHART (fig. 9-3). Such a chart shows how to determine the percentage the lubricating oil is diluted by the fuel oil.

Assume that the viscosity of the new oil (A, in fig. 9-3) is 550 seconds and that of the used oil (B, in fig. 9-3) is 480 seconds. Values A and B are found on the chart and the respective horizontal and vertical lines drawn to the point of intersection, C. The latter point falls on the 2% line, which indicates that the used lube oil has been diluted 2% by the fuel oil.

A lube oil should be changed when it has a 5% dilution. Under certain conditions the oil

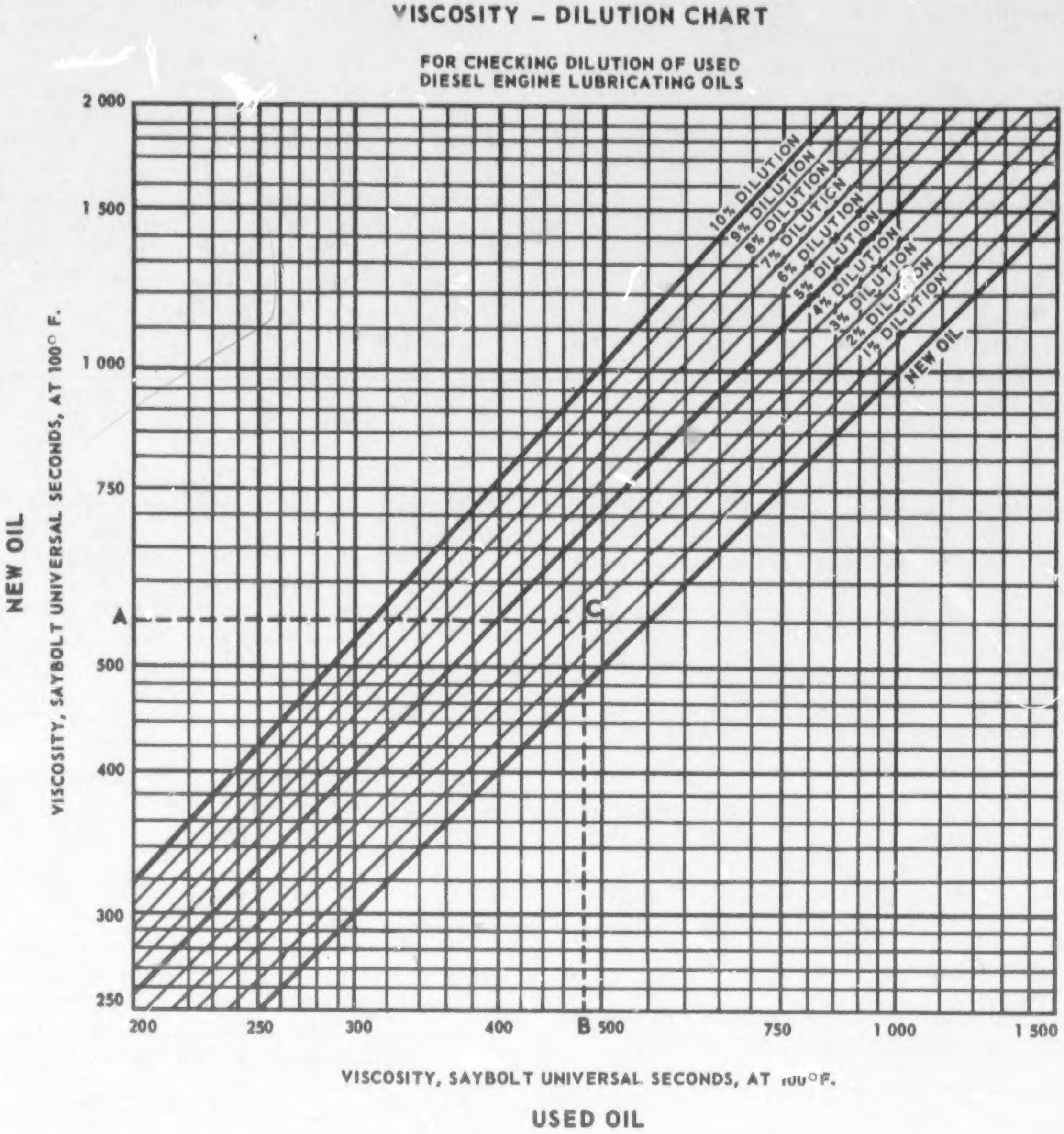

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Figure 9-3.—Lubricating oil dilution chart.

should be changed sooner—if the mechanism is operating under heavy load, or if you are preparing for a long run and therefore may not get a chance to change the oil. Lubricating oil should be tested for fuel dilution once every 4 hours in operating engines and once each week in idle engines.

Conversion of Universal and Furol

Viscosity of lubricating oil is always expressed in Seconds, Saybolt Universal. However, in fuel oil testing, viscosity may be expressed in either Seconds, Saybolt Furol or in Seconds, Saybolt Universal; therefore, you may need to convert from SSF to SSU. For most practical purposes, viscosities between 50 and 100 SSF can be converted into SSU by multiplying by 10. Below 50 seconds, Saybolt Furol, the Saybolt Universal seconds can be determined by referring to the tables of technical data in *Naval Ships' Technical Manual.*

Precautions In Using A Viscosimeter

The precautions you should take when using a Saybolt viscosimeter are as follows:

1. Clean the tube properly before each test.

2. Do not use a drill, or other hard instrument, in the small outlet jet on the tube proper. If it becomes necessary to rid the jet of foreign matter, pull a piece of plaited fishing line lightly back and forth in the jet.

3. Keep the tube covered when the instrument is not in use.

4. Remove soot by boiling the tip of the heater in water; be careful not to wet the electrical connection. After boiling, you can easily rub off the soot.

5. See that the temperature of the bath is not raised higher than the scale of the thermometer being used.

POUR POINT

The lowest temperature at which an oil will barely flow from a container is known as the pour point. This property is closely related to viscosity and the paraffin content; an oil of high viscosity will have a higher pour point than one of low viscosity, and the higher the paraffin content the higher the pour point. In cold weather an oil having a high viscosity may be difficult to pump through the lubrication system of an engine, thus causing starting difficulties. The pour point is especially important for oils used with refrigeration units and internal-combustion engines.

FLASHPOINT

The flashpoint of an oil is the lowest temperature at which flammable vapors given off will flash into flame when brought in contact with a flame. The minimum required flashpoints vary from 315° F for the lightest to 510° F for the heaviest forced-feed oils and from 345° F to 525° F for the various engine and cylinder oils.

FIRE POINT

The fire point is the lowest temperature at which the vapors given off by the oil will continue to burn when ignited.

AUTOGENOUS IGNITION POINT

The temperature at which flammable vapors given off from an oil will burn without the application of a spark or flame is known as the autogenous ignition point. For most lubricating oils, the autogenous ignition temperature is in the range of 465° to 815° F.

Lubricating oil with an autogenous ignition point (ignition temperature) of 465° F will spontaneously ignite if a portion of it (or its vapors) comes in contact with temperatures around 500° F. The same oil is capable of being ignited with a match or a spark in temperatures as low as 350° F (fire point), and the oil will flash across the surface when cooled to 315° F (flashpoint).

CARBON RESIDUE

The carbon that remains in a lubricating oil after the volatile matter evaporates is known as the carbon residue of an oil. The carbon-residue test indicates the amount of carbon that may be deposited in an engine by an oil. Excessive carbon in an engine leads to operating difficulties. The ability of an oil to prevent accumulation of carbon deposits in an engine is known as the detergent power, or DETERGENCY, of the oil.

NEUTRALIZATION NUMBER

The neutralization number of an oil indicates its acid content and is defined as the number of milligrams of potassium hydroxide (KOH) required to neutralize 1 gram of the oil. All petroleum products deteriorate (oxidize) in air and heat. Oxidation produces organic acids which, if present in sufficient concentration will cause deterioration of (1) alloy bearings at elevated temperatures, (2) galvanized surfaces, and (3) the demulsibility of the oil with respect to freshwater and saltwater. The increase in acidity with use is an index of deterioration and is measured as a part of the work factor test. This test is not applicable to Military 9000 series oils.

Modified Neutrality (Qualitative)

The modified neutrality test as outlined below is used to determine whether a used 9000 series oil should be discarded. Place 50 milliliters (ml) of used 9000 series oil sample, 15 ml of distilled water and 3 drops of 0.1% solution methyl orange in a centrifuge tube (fig. 9-4). Stopper the tube, shake vigorously for 30 seconds, and centrifuge for 10 minutes at not less than 1,450 rpm. Remove the centrifuge tube and observe the color of the lower aqueous layer. Report the result of the test as neutral if no pink or red color is apparent. Report the result as acid if the color is pink or red.

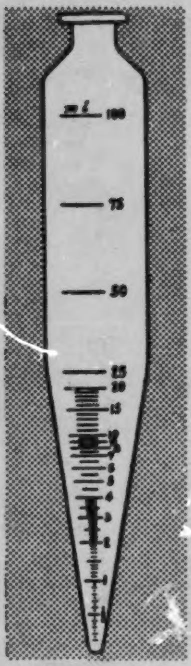

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Figure 9-4.—Centrifuge tube.

PRECIPITATION NUMBER

The precipitation number of an oil is a measure of the water and sediment contained in the oil. The test uses the principle of centifugal force. Water and sediment in oil are heavier than the oil. If the oil containing water and sediment is whirled, the water and suspended solids will go to the outside. The instrument which tests the oil is known as a CENTRIFUGE; it is used to whirl test tubes filled with samples of the oil containing water and sediment so that the oil can be separated from the water and sediment.

The tubes are either pear-shaped or cone-shaped bottles that fit into rubber seats, or jackets on the centrifuge. If the centrifuge has more than two jacket spaces, place the tubes exactly opposite each other to maintain the balance of the mechanism while it is rotating.

The tubes are graduated, or marked, in milliliters (ml) and tenths of a milliliter. The tubes hold 100 ml each. A centrifuge tube, illustrated in figure 9-4, is graduated from bottom to top as follows:

Range (milliliters)	Scale of divisions (milliliters)	Numbered (milliliters)
0-4	0.1	0.5,1,2,3,4
4-10	0.5	5,6,7,8,9,10
10-20	1.0	10,15,20
20-25	5.0	20,25
25-100	25.0	25,50,75,100

In testing for bottom sediment and water, proceed as follows:

1. Measure 50 ml of 90% benzol into each of two centrifuge tubes; add to each tube 50 ml of the oil to be tested.

2. Close the tubes tightly and shake vigorously until the contents are thoroughly mixed.

3. Place the tubes in a water bath, maintained at 120° F, and leave the tubes immersed (to the 100-ml mark on the tube) for 10 minutes.

4. Place the tubes opposite each other in the centrifuge and rotate them for 10 minutes.

5. Read and record the combined volume of water and sediment at the bottom of each tube. (If necessary, estimate to 0.1 ml.)

6. Replace the tubes in the centrifuge, repeat the whirling for 10 minutes, and remove for reading of the volume of water and sediment as before. Repeat this operation until the combined volume of water and sediment in each tube remains constant for three consecutive readings.

7. Read the combined total volume of water and sediment in each tube and estimate to 0.1 ml, if necessary. The sum of these two readings should be recorded as the percentage of the water and sediment in the oil.

If you proceed with care and pay attention to details, duplicate determinations of water and sediment by this method should not differ by more than 0.2 ml.

SPECIFIC GRAVITY

The ratio of the weight of a given volume of any substance in air to the weight of an equal volume of water is known as the specific gravity of a substance. For a liquid, the specific gravity is determined by a hydrometer—a small glass instrument which looks somewhat like a thermometer. This instrument is immersed in a glass container of the liquid and the specific gravity is read directly on the hydrometer scale at the level of the liquid.

The American Petroleum Institute (API) scale is used to measure the specific gravity of the oil. When you test an oil for specific gravity, be sure to thoroughly stir the oil and see that there are no air bubbles. In addition, see that all materials are clean and that the instrument, oil, and container are all at room temperature.

RECOMMENDED OILS

Selection of the proper lubricant is extremely important, because each unit should be supplied with the oil best suited to its operating conditions, speed, size, and bearing pressure. Proper selection is also important in that all similar units should use the same grade of oil; this will reduce the variety of grades to be carried in stock and will decrease the number of possible mistakes in delivery and mixing of dissimilar oils in tanks. Consult the manufacturers' technical manuals and the list of lubricants aboard, if provided, for the proper Navy symbol oil for specific equipment.

CLASSIFICATION AND IDENTIFICATION OF ENGINE OIL

Lubricating oils approved by the Naval Sea Systems Command for use in marine engines are divided into several SERIES, or classes. Each series and each oil within the series is identified by a SYMBOL NUMBER.

The numbers assigned to oils used by the Navy make it easy to identify the oils for proper use and viscosity. Generally, each number consists of four digits; a letter suffix may be used to further identify an oil. The first digit of the number classifies the oil according to use; the last three digits indicate the oil's viscosity. For example, symbol 9110 describes an oil of the 9000 series (an additive type of heavy duty oil) with a viscosity of 110 seconds, Saybolt Universal, when the oil is heated to 210°F.

ADDITIVE ENGINE OILS

Compounded or additive type lubricating oils, sometimes called detergent oils, consist of a base mineral oil to which chemical additives have been added. The performance of the base lubricant is improved by the additives, which inhibit oxidation, improve the natural detergent property of the oil, and improve the tendency of the oil to adhere to metal surfaces.

In modern internal-combustion engines, the lubricating oil must have both detergency and resistance to oxidation to give satisfactory operation with respect to engine wear, engine cleanliness, and oil life. The symbol 9000 series of lubricating oils meet these requirements. Developed primarily for lubrication of high-speed, high-output, diesel engines, these additive-type oils are now used in most internal-combustion engines. The additive-type oils reduce bearing wear, corrosion, carbon and gummy deposits throughout the lubrication system and on the piston rings. These are a number of factors related to the use of additive-type oils which you should keep in mind when operating and maintaining an engine.

Mixing Possibilities

All Navy-approved engine oils may be mixed without harmful effects. For maximum benefit from additive-type oils, however, do not mix them with straight mineral oils, except in emergencies. Mixing of the two types of oil will greatly reduce the additive concentration. Nevertheless, a mixture of additive-type oil and mineral oil will provide better lubrication than straight mineral oil in places where a detergent oil is recommended. When mixing oils of two different viscosities, remember that the viscosity of the mixture will be different from that of either oil.

Noncorrosive Characteristics And Corrosion

Lubricating oils of the 9000 series are noncorrosive to all types of alloy bearings and all metals used in an engine. If bearing surfaces are found to be corroded, the oil has probably been contaminated with either water or partially burned fuel. When corrosion is found in an engine, steps must be taken to eliminate the source of trouble. Fuel systems must be kept in good repair and adjustment at all times. Every possible precaution should be taken to prevent the entrance of an appreciable quantity of water into the lubricating system.

Water in a lubricating oil can usually be detected by the cloudy appearance of the oil and by small droplets of water that may separate in a sample bottle. A small quantity of freshwater in oil will cause no difficulty because it usually evaporates when the oil passes through the hot engine. However, when serious water contamination exists, the oil should be drained and replaced with fresh oil after the source of the leak has been discovered and repaired.

Changes In Color

Detergent oils change color, normally turning dark after a few hours of use. The change in color is due to the suspension of fine particles of fuel soot which accumulate in the oil. The change in color does not necessarily indicate a reduction in the lubricating quality of the oil.

GREASES

Operating temperatures, the rate at which lubrication must be supplied, and the design of the equipment may make the use of oil impractical. Greases are used at points where oil will not provide proper lubrication. Machinery manufacturers provide either pressure or cup fittings for applying the grease. The location of grease fittings and the type of grease required are shown on machinery lubrication charts and in manufacturers' technical manuals. You MUST follow lubrication instructions, since some greases are for general use and others are for special purposes. You will better understand maintenance problems involving lubrication if you are familiar with the principal factors of the composition and classification of greases. Information on greases is given in *Fireman*, NAVEDTRA 10520-E and in *NavShips' Technical Manual*, chapter 262 (9450).

PURIFICATION OF LUBRICATING OIL

Oil must be clean before it goes into the lubricating system of an engine, and it must also be cleaned or purified regularly while being recirculated through the engine. Dust and dirt particles from the intake air get into the oil system. Bits of metal from the engine parts are picked up and carried in the oil. Carbon particles from combustion in the cylinders work into the oil, even in the best engines. The oil itself deteriorates and leaves some sludge and gummy material which circulates through the oil system. Some water will get into the oil, even when precautions are taken.

Contamination must be removed or the oil will not meet the requirements of lubrication. Dirt and other hard particles score and scratch the rubbing metal surfaces within the engine. This abrasive action greatly increases friction which adds heat to the moving parts and causes them to wear faster. Sludge and water interfere with the oil's ability to hold a good lubricating film between the rubbing surfaces within the engine.

Several devices are used to keep the oil as pure as possible. Each device is designed to remove certain kinds of contamination. Therefore, several types of devices are required in the lubricating oil system to maintain the oil in the best possible condition. Strainers, filters, settling tanks, and centrifugal purifiers are the main devices used to keep the oil free of contamination. We will now consider settling tanks and purifiers with emphasis on purifiers.

SETTLING TANKS AND PURIFIERS

The lubricating system of many shipboard diesel engine installations includes settling tanks (used-oil tanks). These tanks allow the oil to stand while accumulated water and other impurities settle. Settling is due to the force of gravity. A number of layers of contamination may form, the number depending on the different specific gravities of the various substances which contaminate the oil. Settling takes place more rapidly and efficiently when the oil is heated.

Although settling tanks do remove much contamination from lubricating oil, most ships have additional equipment to remove water and impurities that are not removed by other devices. These machines are usually called purifiers but are frequently also referred to as centrifuges.

The manufacturer furnishes detailed instructions with each purifier on its construction, operation, and maintenance. When you are responsible for the operation and maintenance of a purifier, study the manufacturer's instructions and follow them carefully. The following provides general information on the methods of purification and the principles of operation of purifiers.

Methods of Purification

On diesel-propelled ships, the piping system is generally arranged to permit two methods of purifying: batch purification and continuous purification.

BATCH PROCESS.–The batch purification process is used when an engine is secured. The lubricating oil is transferred from the sump to a settling tank by a transfer pump. The oil is heated by steam heating coils in the settling tank and maintained at a temperature of approximately 175° F for several hours. Water and other settled impurities are drained from the settling tank through a valve. The oil is then centrifuged and discharged back into the sump from which it was taken.

CONTINUOUS PROCESS.–The continuous purification process is used when an engine is operating. The centrifugal purifier takes suction from a sump tank and, after purifying the oil, discharges the purified oil back to the same sump.

Principles of Purifier Operation

Centrifugal force is the principle used in purifying oil. Centrifugal force is force exerted upon a body or substance by rotation; it impels the body or substance outward from the axis of rotation.

A centrifugal purifier is essentially a container which is rotated at high speed while contaminated oil is forced through, and rotates with, the container. The centrifugal force imposed on the oil by the high rotating speed of the container separates the suspended foreign matter from the oil. However, only materials that are insoluble in one another can be separated by centrifugal force. For example, JP-5 or diesel fuel cannot be separated from lubricating oil, nor can salt be removed from seawater by centrifugal force. Water, however, can be separated from oil because water and oil do not form a true solution when mixed. Furthermore, there must be a difference in the specific gravities of the materials to be separated by centrifugal force.

When a mixture of oil, water, and sediment stands undisturbed, gravity tends to form an upper layer of oil, an intermediate layer of water, and a lower layer of sediment. The layers form because of specific gravities of the material in the mixture. If the oil, water, and sediment are placed in a container which is revolving rapidly around a vertical axis, the effect of gravity is negligible in comparison with that of the centrifugal force. Since centrifugal force acts at right angles to the axis of rotation of the container, the sediment with its greater specific gravity assumes the outermost position, forming a layer on the inner surface of the container. Water, being heavier than oil, forms an intermediate layer between the layer of sediment and the oil, which forms the innermost layer. The separated water is discharged as waste, and the oil is discharged for reuse. The solids remain in the rotating unit. The purifier is cleaned manually when necessary.

Separation by centrifugal force is further affected by the size of the particles, the viscosity of the fluids, and the time during which the materials are subjected to the centrifugal force. In general, the greater the difference in specific gravity between the substances to be separated and the lower the viscosity of the oil, the greater will be the rate of separation.

Use of Purifiers

Centrifugal purifiers are used to purify both fuel oil and lubricating oil. A purifier may be used to remove both water and sediment from oil or to remove sediment only. When water is involved in the purification process, the purifier is usually called a SEPARATOR. When the principal item of contamination is sediment, the purifier is used as a CLARIFIER. Purifiers are generally used as separators for purifying fuel oils. When used to purify a lubricating oil, a purifier may be used as either a separator or a clarifier. Whether a purifier is used as a separator or a clarifier depends on the moisture content of the oil being purified.

An oil which contains no moisture needs only to be clarified since the oil will be discharged in the purified state after the solids deposit in the bowl of the purifier. If, however, the oil contains some moisture, the continued feeding of "wet" oil into the bowl will eventually result in a bowl filled with water;

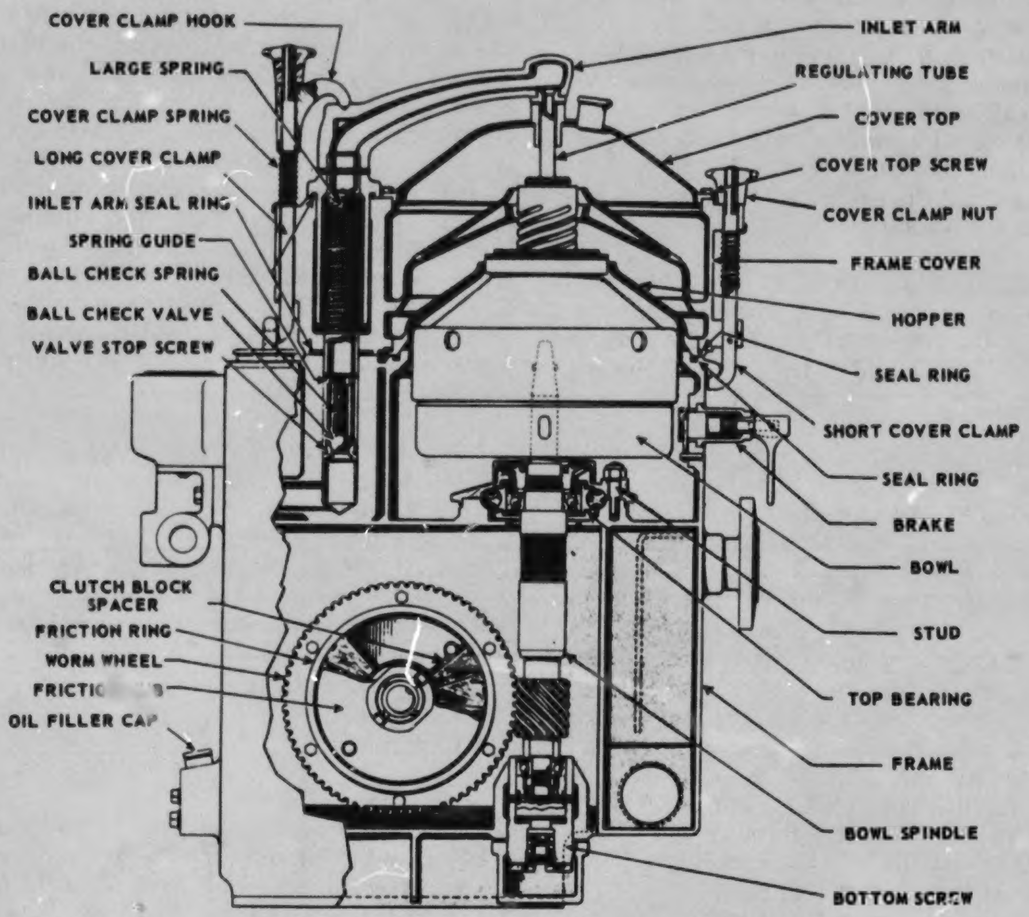
COVER CLAMP HOOK
LARGE SPRING
COVER CLAMP SPRING
LONG COVER CLAMP
INLET ARM SEAL RING
SPRING GUIDE
BALL CHECK SPRING
BALL CHECK VALVE
VALVE STOP SCREW
CLUTCH BLOCK SPACER
FRICTION RING
WORM WHEEL
FRICTIC B
OIL FILLER CAP
INLET ARM
REGULATING TUBE
COVER TOP
COVER TOP SCREW
COVER CLAMP NUT
FRAME COVER
HOPPER
SEAL RING
SHORT COVER CLAMP
SEAL RING
BRAKE
BOWL
STUD
TOP BEARING
FRAME
BOWL SPINDLE
BOTTOM SCREW

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Figure 9-5.—Disk-type centrifugal purifier.

from that time on, the centrifuge is not accomplishing any separation of water from the oil. Even before the bowl is completely filled with water, the layer of water in the bowl reduces the depth of the oil layer. As a result, the incoming oil passes through the bowl at an increased velocity. Because of this, the liquid is subject to centrifugal force for a shorter time; the separation of water from the oil is, therefore, not as complete as it would be if the bowl were without the water layer, or if the water layer were shallow. For this reason the centrifuge should NOT be operated as a clarifier unless the oil contains little or NO water. A small amount of water can be accumulated, together with the solids, and drained when the bowl is stopped for cleaning; if there is any appreciable amount of water in the oil, however, the purifier should be operated as a separator.

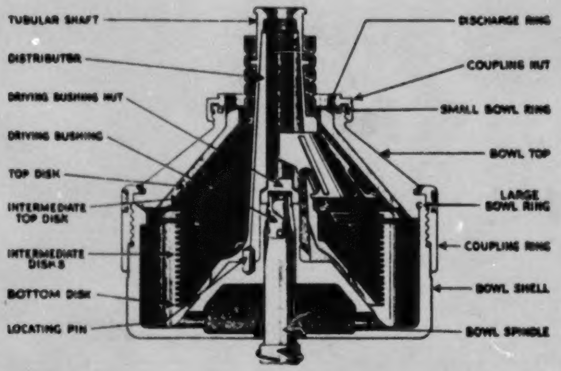
Types of Centrifugal Purifiers

There are two types of purifiers used in Navy installations. Both types operate on the same general principle. The principal difference between the two types of purifiers is in the design of the rotating units. In the tubular-type purifier, the rotating element is a hollow tubular rotor; in the disk-type purifier, the rotating element is a bowl-like container which encases a stack of disks.

DISK-TYPE CENTRIFUGAL PURIFIER.–A sectional view of a disk-type centrifugal purifier is shown in figure 9-5. The bowl is mounted on the upper end of the vertical bowl spindle which is driven by a worm wheel and a friction clutch assembly. A radial thrust bearing at the lower end of the bowl spindle carries the weight of the bowl spindle and absorbs any thrust created by the driving action. The flexible mount of the top bearing allows the bowl to come to the center of rotation.

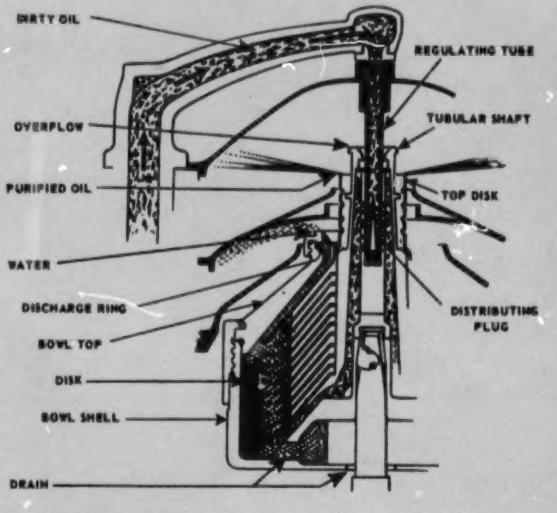
The parts of a disk-type bowl are shown in figure 9-6. The flow of oil through the bowl and other parts is shown in figure 9-7.

Contaminated oil enters the top of the revolving bowl through the regulating tube. The oil then passes down the inside of the tubular shaft and out at the bottom into the stack of disks. As the dirty oil flows up through the distribution holes in the disks, the high centrifugal force of the revolving bowl causes the dirt, sludge, and water to move outward; the purified oil moves inward toward the tubular shaft. The disks divide the space within the bowl into many, separate, narrow passages or spaces. The liquid confined within each passage is restricted so that it can flow only along the passage. This arrangement prevents excessive agitation of the liquid as it passes through the bowl and creates shallow settling distances between the disks.


TUBULAR SHAFT
DISTRIBUTOR
DRIVING BUSHING NUT
DRIVING BUSHING
TOP DISK
INTERMEDIATE TOP DISK
INTERMEDIATE DISKS
BOTTOM DISK
LOCATING PIN
DISCHARGE RING
COUPLING NUT
SMALL BOWL RING
BOWL TOP
LARGE BOWL RING
COUPLING RING
BOWL SHELL
BOWL SPINDLE

75.232

Figure 9-6.–Parts of a disk-type purifier bowl.

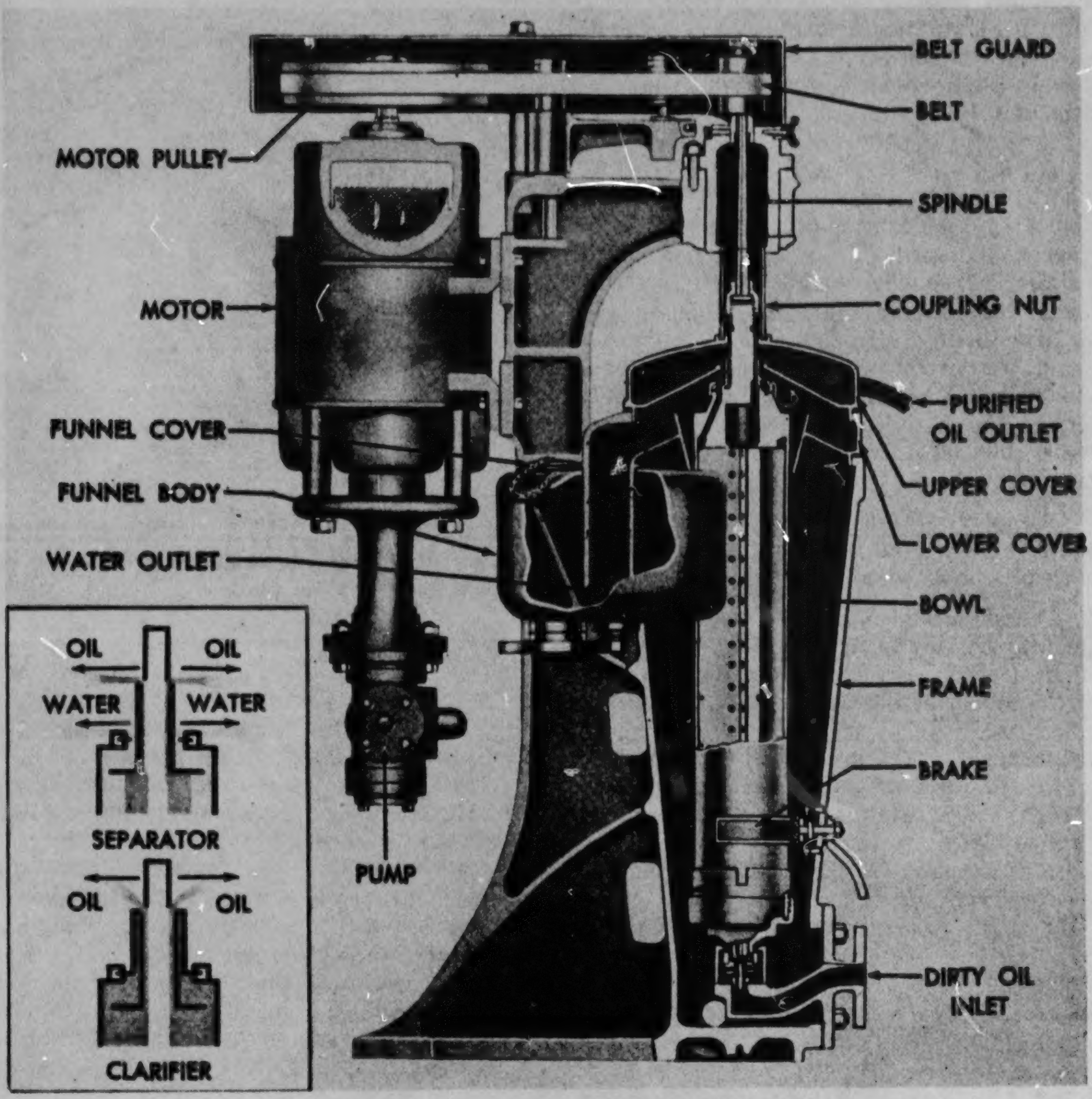

DIRTY OIL
REGULATING TUBE
OVERFLOW
TUBULAR SHAFT
PURIFIED OIL
TOP DISK
WATER
DISCHARGE RING
DISTRIBUTING PLUG
BOWL TOP
DISK
BOWL SHELL
DRAIN

75.233

Figure 9-7.–Path of contaminated oil through a disk-type purifier bowl.

Most of the dirt and sludge remains in the bowl, collecting in a layer on the inside vertical surface of the bowl shell. Water, along with some dirt and sludge separated from the oil, is discharged through the discharge ring at the top of the bowl. The purified oil flows inward and upward through the disks, discharging from the neck of the top disk (fig. 9-7).

TUBULAR-TYPE CENTRIFUGAL PURIFIER.–A cross section of a tubular type centrifugal purifier is shown in figure 9-8. A purifier of this type consists essentially of a rotor, or bowl, which rotates at high speeds. The rotor has an opening in the bottom through which the dirty lubricating oil enters and two sets of openings in the bowl top through which the oil and water (in a separator action) or the oil alone (in a clarifier action) discharges. (See inset, fig. 9-8.) The bowl, or hollow rotor, of the


BELT GUARD
BELT
MOTOR PULLEY
SPINDLE
MOTOR
COUPLING NUT
PURIFIED OIL OUTLET
FUNNEL COVER
UPPER COVER
FUNNEL BODY
LOWER COVER
WATER OUTLET
BOWL
OIL
OIL
WATER
WATER
FRAME
BRAKE
SEPARATOR
PUMP
OIL
OIL
DIRTY OIL INLET
CLARIFIER

75.234

Figure 9-8.—Tubular-type centrifugal purifier.

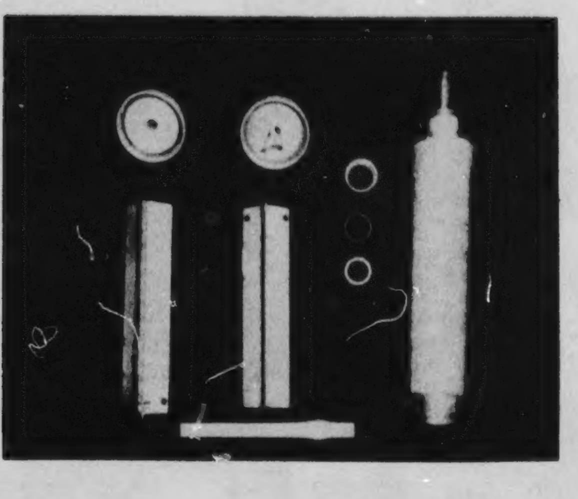
purifier is connected by a coupling unit to a spindle suspended from a small bearing assembly. The bowl is belt driven by an electric motor mounted on the frame of the purifier.

The lower end of the bowl extends into a flexible mounted drag bushing. The drag bushing in the drag bushing assembly restrains movement of the bottom of the bowl; it allows sufficient movement, however, so that the bowl can balance itself about its center of rotation when the purifier is in operation. Inside the bowl is a device consisting of three flat plates which are equally spaced radially. This device is commonly called the three-wing device, or just the three-wing. The three-wing rotates with the bowl and forces the liquid in the bowl to rotate at the same speed as the bowl. The liquid to be centrifuged is fed into the bottom of the bowl, through the feed nozzle, under pressure so that the liquid jets into the bowl in a stream.

When the purifier is used as a lubricating oil separator or clarifier, the feed jet strikes against a cone which is placed on the bottom of the three-wing; this brings the liquid up to bowl speed smoothly, without making an emulsion. The cone is not necessary when the purifier is used as a separator with fuel oil, because fuel does not have the tendency to emulsify. Both types of three-wing devices are shown in figure 9-9.

In a tubular-type purifier, the process of separation is the same as in the disk-type purifier. In both types of purifiers, the separated oil takes the innermost position and the separated water moves outward. Both liquids are discharged separately from the bowls; solids separated from the liquid are retained in the bowls.

Even though similar in operation, the two types of purifiers differ somewhat in design. The bowl of a tubular-type purifier has a small diameter and is operated at a high speed. The length of the tubular bowl (the distance the liquid travels through the bowl) is many times the depth of the liquid layer (settling distance). The disk-type bowl has a larger diameter and a much shorter length; the distance the liquid travels in passing through such a bowl is not much greater than the settling distance. Tubular bowls are fed through a feed nozzle at the bottom of the bowl. Disk-type bowls are ordinarily fed from the top through a center tube which directs the liquid toward the distribution holes in the disk stack. Disks are provided to set up layers, thereby reducing settling distance. (See fig. 9-6 and 9-7.)



75.235

Figure 9-9.—Parts of a tubular-type purifier bowl.

Operation of Purifiers

Specific directions for operating a purifier should be obtained from the manufacturer's instructions provided with the unit. The following information is general and applies, in the main, to both types of purifiers.

For maximum efficiency, purifiers should be operated at their maximum designed speed and rated capacity. An exception to operating a purifier at designed rated capacity is when the unit is used as a separator with 9000 series detergent oil. Some engines using the 9000 series oils are exposed to large quantities of water. When the oil becomes contaminated with water, it has a tendency to emulsify. The tendency to emulsify is most pronounced when the oil is new and gradually decreases during the first 50 to 75 hours of engine operation. During this period, the purifier capacity should be reduced to approximately 80% of the rated capacity.

When a purifier is operated as a separator, the bowl MUST BE PRIMED with freshwater before any oil is admitted to the purifier. The water seals the bowl and creates an initial equilibrium of liquid layers. If the bowl is not primed, the oil will be lost through the water discharge ports.

INFLUENCING FACTORS IN PURIFIER OPERATION

There are several factors which influence purifier operation. The time required for purification and the output of a purifier depend on such factors as the viscosity of the oil, the pressure applied to the oil, the size of the particles of sediment, the difference between the specific gravity of the oil and that of the substances which contaminate the oil, and the tendency of the oil to emulsify.

The viscosity of the oil determines to a great extent the length of time required for purification of lubricating oil. The more viscous the oil, the longer the time required to purify it to a given degree of purity. Heating the oil to decrease the viscosity of the oil is one of the most effective methods to aid purification.

Even though certain oils may be satisfactorily purified at operating temperatures, a greater degree of purification will generally result if the oil is heated to a high temperature. To accomplish this, the oil is passed through a heater to obtain the desired temperature before the oil enters the purifier bowl.

Most oils used in Navy installations can be heated to 180° F without damage to the oils. Prolonged heating at higher temperatures is not recommended because such oils tend to oxidize at high temperatures. Oxidation results in rapid deterioration. In general, oil should be heated enough to produce a viscosity of approximately 90 seconds, Saybolt Universal (90 SSU), but the temperature should not exceed 180° F. The temperatures recommended for purifying oils in the 9000 series are:

Military Symbol	Temperature (°F)
9110	140°
9170	160°
9250	175°
9500	180°

Pressure should not be increased above normal to force a high viscosity oil through the purifier. Instead, the viscosity should be decreased by heating the oil. Pressure in excess of that normally used to force oil through the purifier will result in less efficient purification. On the other hand, a reduction in the pressure that forces the oil into the purifier will increase the length of time the oil is under the influence of centrifugal force and, therefore, will tend to improve results.

Discharge Ring (Ring Dam)

If the oil discharged from a purifier is to be free of water, dirt, and sludge and if the water discharged from the bowl is not to be mixed with oil, the proper size discharge ring (ring dam) must be used. The size of the discharge ring depends on the specific gravity of the oil being purified; diesel fuel oil, JP-5, and lubricating oils all have different specific gravities and, therefore require different sized discharge rings. While all discharge rings have the same outside diameter, their inside diameters vary. Ring sizes are indicated by even numbers; the smaller the number, the smaller the ring size. The inside diameter in millimeters is stamped on each ring. Sizes vary in increments of 2 millimeters. Charts, provided in manufacturers' technical manuals, specify the proper ring size to be used with an oil of a given specific gravity. Generally, the ring size indicated on such a chart will produce satisfactory results. If the recommended ring fails to produce satisfactory purification, it will be necessary to determine the correct size by trial-and-error. In general, the most satisfactory purification of the oil is obtained when the ring is the largest size that can be used without losing oil along with the discharged water.

Maintenance of Purifiers

The bowl of a purifier must be cleaned daily in accordance with the PMS, and all sediment must be carefully removed. The amount of dirt, grit, sludge, and other foreign matter in the oil may warrant more frequent cleaning. If the amount of foreign matter in an oil is not known, the purifier should be shut down and examined and cleaned once each watch, or more often if necessary. The amount of sediment found in the bowl indicates how long the purifier may be operated between cleanings.

Periodic tests should be made to ensure that the purifier is working properly. When the oil in the system is being purified by the batch process, tests should be made at approximately 30-minute intervals. When the continuous process of purification is used, tests should be made once each watch. Analysis of oil drawn from the purifier is the best method of determining the efficiency of the purifier; however, the clarity of the purified oil and the amount of oil discharged with the separated water will also indicate whether the unit is operating satisfactorily.

LUBRICATING OIL SYSTEMS

The reliability and performance of modern diesel engines are directly dependent on the effectiveness of their lubricating systems. The primary functions of lubrication are to minimize friction between the bearing surfaces of moving parts and to dissipate heat. Another function is to keep internal engine parts clean by removing carbon and other foreign matter. The system that supplies the oil for these functions in practically all modern internal-combustion engines is of the pressure type. Even though many variations exist in the details of engine lubricating systems, the parts of such a system and its operation are basically the same.

PARTS OF A LUBRICATING OIL SYSTEM

You might think of the lubricating system of an engine as consisting of two main divisions, the external to the engine and that within the engine. The internal division, or engine part, of the system consists mainly of passages and piping; the external part of the system includes several components which aid in supplying the oil in the proper quantity, at the proper temperature, and free of impurities. External to the engine, the lubricating systems of many engines include such parts as tanks and sumps, pumps, coolers, strainers and filters, and purifiers.

TANKS AND SUMPS

The lubricating systems of propulsion installations use tanks to collect and recirculate oil after it has been used for lubrication and cooling. Some installations have a sump or drain tank under the engine to collect the oil as it drains from the engine crankcase. Storage and sump tanks are not common in auxiliary engines; these engines generally contain the oil supply directly within the engine oil pan.

PUMPS

Positive-displacement, rotary-gear type pumps deliver oil under pressure to the various parts of the engine. Since the pumps are driven from the engine camshaft or, in some engines, directly from the crankshaft, the oil is supplied at pressures adjusted to the needs of the engine. Changes in engine speed cause corresponding changes in pump output.

Detached lubricating pumps on large diesel engines supply the purifier, fill the sump tanks from the storage tanks, and flush and prime the lubricating oil system. You should be thoroughly familiar with the lubricating oil system before attempting to transfer oil or to flush and prime the engine. When priming or flushing the engine, you should know that prolonged flushing or priming of the lubricating oil system on any engine may cause oil to accumulate in the air intake passages and cause overspeeding upon starting. To prevent this, you must observe the following precautions.

1. Prime the engine lubricating oil system before the engine is turned over by hand or by motor driven jacking gear. This ensures that a film of oil is deposited to prevent friction when parts start to move.
2. Continue to prime the engine ONLY until the engine lubricating oil pressure gage registers a slight pressure or until you see oil at each main bearing.
3. Before starting the engine after a prolonged shutdown, inspect the air receiver and blower discharge passages and remove any accumulation of lubricating oil.

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The pressure maintained by most lubricating oil pumps is controlled by pressure-regulating valves or pressure-relief valves built directly into the pump. In some pumps, pressure-relief valves are separate from the pump and are used for pressure control purposes. Most oil pressure-regulating devices recirculate excess oil back to the pump. Some pumps, however, discharge excess oil directly into the engine sump or the crankcase.

COOLERS

The lubricating oil systems of most engines, especially large ones, use coolers (heat exchangers) to maintain the oil temperature within the most efficient operating temperature range. Oil, passing through the operating engine, absorbs heat from the metal parts. Since engine oil is recirculated and used over and over, it is continually absorbing additional heat. Unless the heat is removed, the oil temperature will rise to excessive values. At extremely high temperatures, oil tends to oxidize rapidly and form carbon deposits. Excessive temperatures also cause an increase in the rate of oil consumption. Consequently, oil coolers are required to remove excess heat from the oil to retain its lubricating qualities.

The coolers used to remove heat from lubricating oils are of the same type as those used to remove heat from other fluids common to internal-combustion engines. You will find additional information on heat transfer and coolers in Chapter 8 since the liquid to which heat is transferred and the cooler are both commonly associated with the engine cooling system.

FILTERING DEVICES

The lubricating oil system of an engine uses strainers and filters to remove abrasives and foreign materials which tend to increase wear of engine parts and cause the lubricating oil to deteriorate. A variety of strainers and filters are used in Navy installations. In Navy terminology, all metal-edge and wire-mesh devices are classed as strainers; devices that have replaceable, absorbent cartridges are called filters. Filters remove smaller particles. The location and number of strainers and filters will vary, depending on the type of installation.

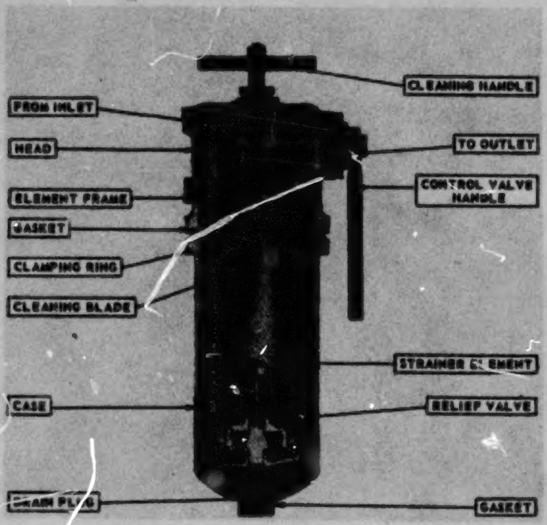
Strainers

Lubricating oil strainers may be either simplex or duplex. A duplex strainer is two strainer elements in one assembly. A manual valve directs the flow of oil through either of the elements. When duplex strainers are used, one element can be bypassed, and the element can be removed and cleaned without disturbing the flow of oil through the other element to the engine.

Every approved lubricating oil strainer has a built-in, spring-loaded or differential area, pressure-relief valve. The valve must be sufficiently large to bypass all of the oil around a clogged strainer to maintain an uninterrupted flow of oil to the engine.

Metal-edge type strainers consist of a strainer element surrounded by a case which serves as a sump to collect foreign material and water. The element has an edge-wound metal ribbon or a series (stack) of edge-type disks. Most strainers have devices for manually rotating the strainer element against metallic scrapers which remove material caught by the element. Strainers usually have vents for releasing air from the system.

EDGE-WOUND METAL RIBBON TYPE STRAINER.—An edge-wound metal ribbon type strainer is shown in figure 9-10. The strainer filters the oil required by the engine except when the element is removed for cleaning or servicing. To remove the element, turn the control valve handle to the BYPASS position, shunting the oil flow through the strainer head; remove the element without interrupting the oil flow to the engine. Under normal operating conditions, the oil comes into the strainer at the top and descends to surround the ribbon



75.191X

Figure 9-10.–Edge-wound metal ribbon type lubricating oil strainer.

element. The oil then passes through the element, into the center, and then upward to the outlet passage.

Another type of element consists of a closely compressed coil of stainless steel wire. The wire has been passed between rollers so that it is a wedge-shaped wire or ribbon with one edge thicker than the other. On one side of the wire, projections are spaced at definite intervals; the other side is smooth. The projections on one side of the wire touch the smooth side of the wire on the adjacent coil to provide appropriate spacing between adjacent coils. The thick edge of the wire is on the outside of the coil; a tapered slot is therefore formed from the outside to the inside of the coil, with the narrowest part of the slot on the outside. With this arrangement, dirt particles small enough to pass through the outside, or narrowest, portion of the slot will not become stuck halfway through the slot and clog the oil flow. The dirt removed from the oil remains on the outside of the element and can be readily removed by rotating the element with the cleaning handle. As the element rotates, the cleaning blade scrapes foreign material from the element.

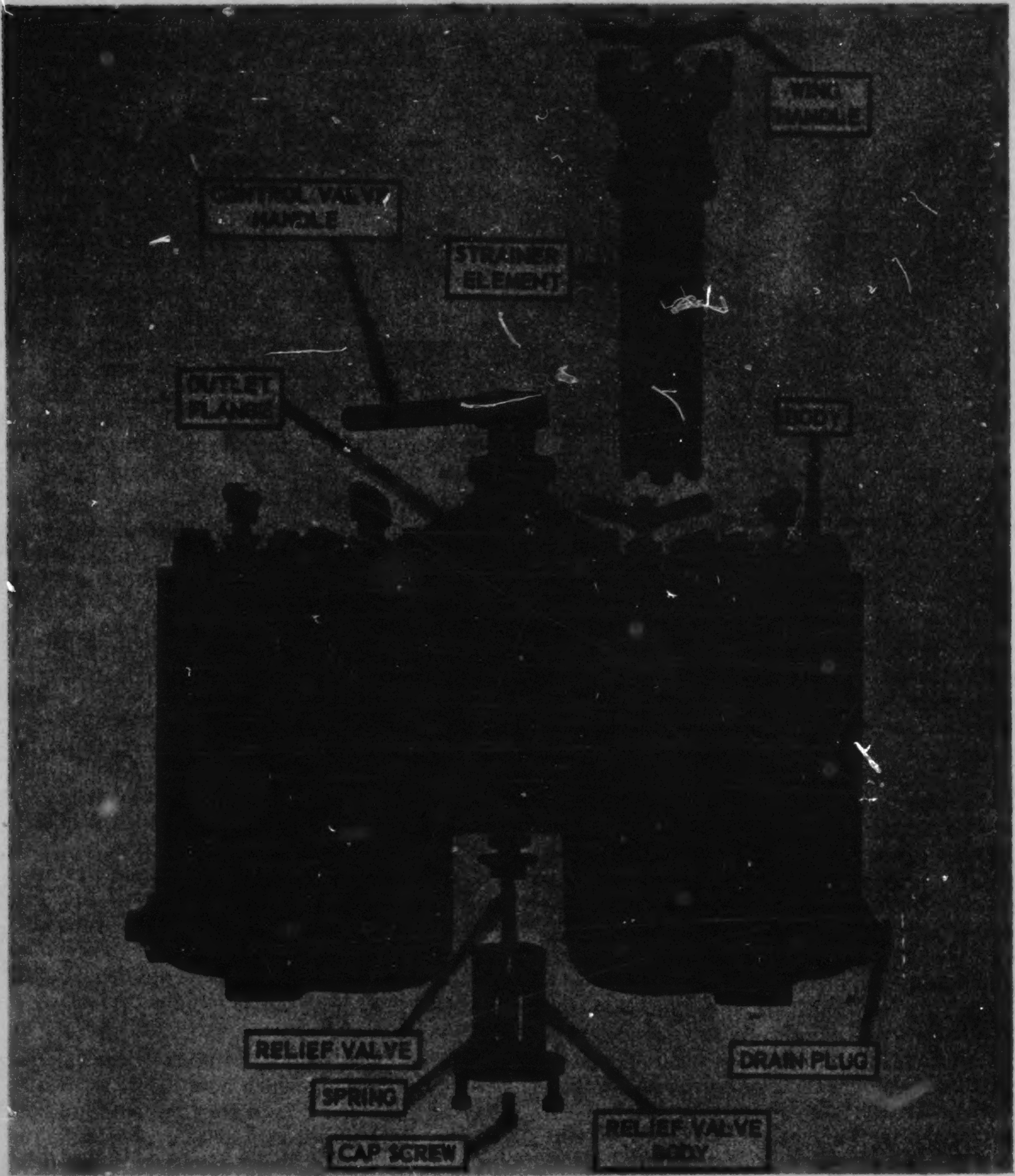
The control-valve handle on the strainer operates the bypass valve. When the handle is in the ON position, the lubricating oil is flowing through the strainer. When the handle is in the BYPASS position, the oil is flowing directly through the head of the unit, and the strainer case and element can be removed and cleaned. The ON and BYPASS positions are indicated on the strainer head.

EDGE-DISK TYPE STRAINER.–A duplex strainer of the edge-disk type is shown in figure 9-11. The strainer consists of two sections, each of which includes three strainer elements. A control valve between the two sections secures one section while the other remains in operation. The secured section acts as a standby unit; it may be opened for cleaning and inspection without interrupting the straining operation.

A strainer element of the edge-disk type consists of an assembly of thin disks separated slightly by spacer disks. The assembly of one type of strainer element is illustrated in figure 9-12.

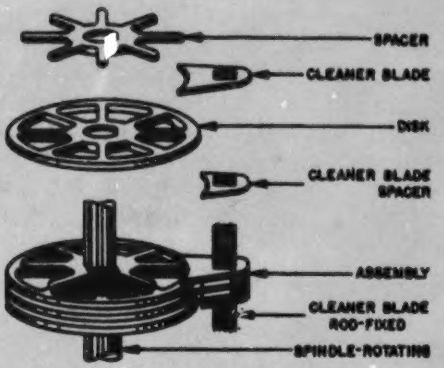
The lower end of a disk assembly is closed; the upper end is open to the strainer discharge. Oil enters the strainer assembly and is forced down between the casing and disk assembly and then through the disks into the center of the disk assembly. The oil then passes up through the assembly and out the discharge outlet. In passing through the strainer, the oil passes through the slots between the strainer disks. A relief valve at the bottom of the strainer element relieves pressure which builds up if the slots become filled with foreign matter. The relief valve bypasses the oil up through the center of the strainer element and out the strainer discharge when a predetermined pressure is reached.

When the assembly is turned by the external handle, the solids which have lodged against or between the disks, are carried around until they meet the stationary cleaner blades. The stationary cleaner blades clean the solids from the strainer surface. The solids are compacted by the cleaner blades and fall into the sump of the strainer. To keep the strainer in a clean, free-filtering condition, give the wing handle


WING HANDLE
CONTROL VALVE HANDLE
STRAINER ELEMENT
OUTLET FLANGE
BODY
RELIEF VALVE
SPRING
CAP SCREW
RELIEF VALVE BODY
DRAIN PLUG

75.192

Figure 9-11.—Edge-disk type oil strainer.



75.193X
Figure 9-12.–Edge-disk type strainer element assembly.

one or more complete turns in a clockwise direction at frequent intervals. It is therefore not necessary to break any connections or to interrupt the flow of oil through the strainer to clean the strainer unit. If the handle turns hard, the strainer surfaces have heavy deposits of solids on them. You should turn the handle frequently; there is no danger of turning the handle too often, as there are no parts to wear out. If turning the handle does not clean the strainer, remove the head and disk assembly and soak them in a solvent until the solids are removed.

WIRE-MESH (SCREEN) TYPE STRAINER.–Strainers installed on the suction or intake side of the pressure pumps are generally of the wire-mesh (screen) type and are referred to as coarse strainers. Some screen-type strainers are located in the oil pan or sump. One type of screen strainer is shown in figure 9-13.

Filters

In filters approved by the Navy, the absorbent material is composed of such substances as cellulose, cotton yarn, cotton waste, and paper disks. Materials such as mineral wood, fuller's earth, and activated charcoal remove the compounds from additive-type oils. Such materials are not permitted in filters used on engines in naval service.

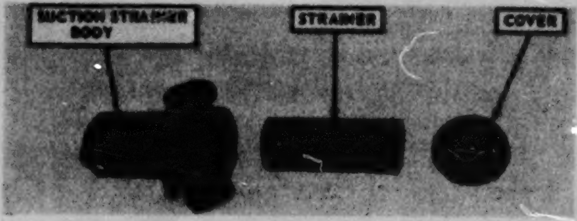


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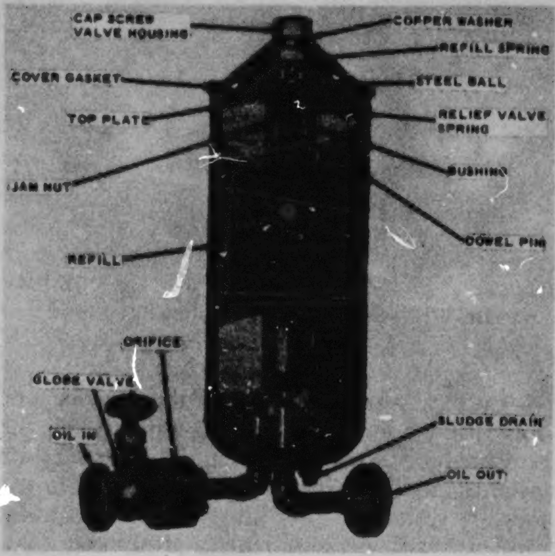
Figure 9-13.–Screen-type lubricating oil strainer.

Lubricating oil filters are of the simplex type only. Filters may be located directly in the pressure-lubricating oil system or they may be installed as bypass filters. When installed in the pressure system, a filter must contain a built-in, spring-loaded, pressure-relief valve. The valve must be large enough to bypass all oil to the engine in case the filter element becomes restricted.

Bypass filters need an orifice plate in the line to the filter to control the amount of oil removed from the lubricating oil pressure system. The amount of oil which flows through a bypass filter is only a small percentage of that flowing through the pressure system. The oil from a bypass filter is returned to the sump tank.

Filters vary as much in design and construction as strainers. Filters may be of the UNIT type or the TANK type. The unit type filter may be a single unit, a double unit, or a triple unit. In double or triple type units, the individual units are connected by manifolds for inlet, discharge, and sludge drain. The tank type filter consists of a single tank that has several filter elements. In some tank type filters, each filter-element holder has a relief valve to protect the element against excessive pressure. Other tank type filters are constructed to withstand pressure greater than that of the relief valve setting on any of the pumps in the lubricating oil system. Examples of a single-unit type filter and a tank type filter are shown in figures 9-14 and 9-15, respectively.

We have discussed only the main parts of an engine lubricating system to this point. You


CAP SCREW
VALVE HOUSING
COPPER WASHER
REFILL SPRING
COVER GASKET
STEEL BALL
TOP PLATE
RELIEF VALVE SPRING
BUSHING
JAM NUT
DOWEL PIN
REFILL
ORIFICE
GLOBE VALVE
SLUDGE DRAIN
OIL IN
OIL OUT

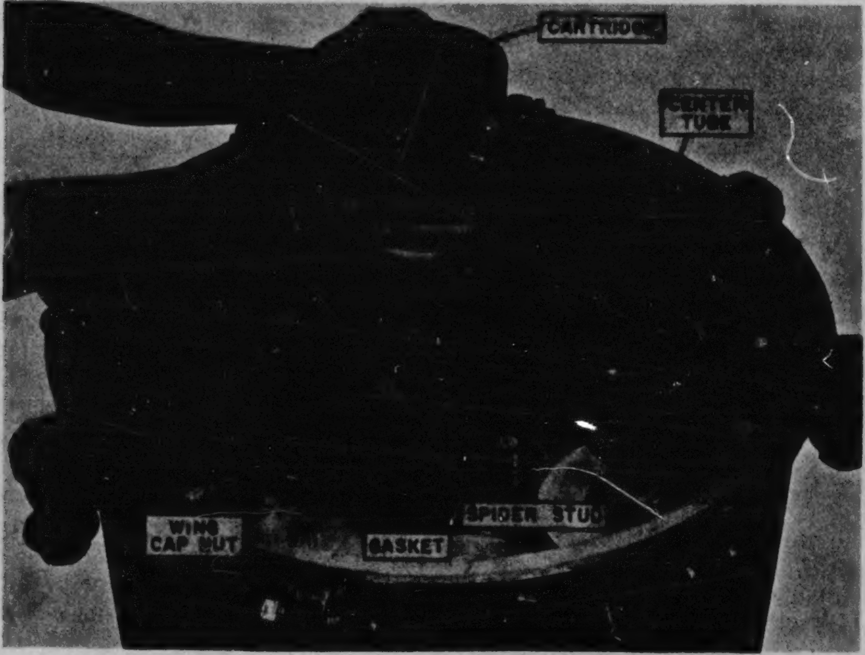
75.195X

Figure 9-14.—A single-unit type lubricating oil filter.

should also be familiar with the piping and the gages, thermometers, and other instruments essential to complete the system. In the remainder of this chapter we shall deal with the types of lubricating oil filtering systems, the path of oil through a lubricating oil system (including the internal or engine part of the system), how and why lubricating oil systems are ventilated, and methods of purifying lubricating oil.

LUBRICATING OIL FILTERING SYSTEMS

The strainers and filters used with Navy diesel engines are a part of what is generally referred to as the lubricating oil filtering system. An engine used by the Navy may use one of four types of filtering systems: shunt, full-flow, sump, and bypass. The type of filtering system used depends on the type of installation and its application.


CARTRIDGE
CENTER TUBE
SPIDER STUD
WING CAP NUT
GASKET

75.196

Figure 9-15.—Tank-type lubricating oil filter.

SHUNT FILTERING SYSTEM

In a shunt-type filtering system, a pressure pump takes the oil from the sump and discharges it first through a strainer, then through a filter, and finally through a cooler to the engine. The pump delivers a constant amount of oil per revolution, but the resistance in the strainer and the filter varies, depending on the condition of these units and the temperature of the oil. To ensure an adequate flow of oil to the engine at any particular engine speed, the filter and the strainer each have a bypass fitted with a spring-loaded bypass valve through which a portion of the oil flows.

If the filter becomes clogged or if the oil is cold, a relatively large portion of the lubricating oil is shunted through the bypass. Strainers and filters in a shunt-type filtering system may also be manually bypassed. Each bypassing unit has three-way valves so that the strainers may be cleaned or filter elements may be replaced while the engine is operating. A schematic diagram of a shunt-type filtering system is shown in figure 9-16.

FULL-FLOW FILTERING SYSTEM

The full-flow filtering system is used in most new constructions. It is similar to the shunt-type system except that the filter elements are designed for high flow rates permitting the entire pump delivery to pass through the elements. The bypass valve has the same function as in the shunt system; however, the valve will remain closed during normal engine operation. A schematic arrangement of a full-flow filtering system is shown in figure 9-17.

In some later installations, the lube oil strainer is located after the lube oil cooler, and the relief valve for the lube oil filter is external. The lube oil strainer was moved because, on some occasions, the cooler was not cleaned properly and dirt from the cooler was carried directly into the engine, damaging the bearings.

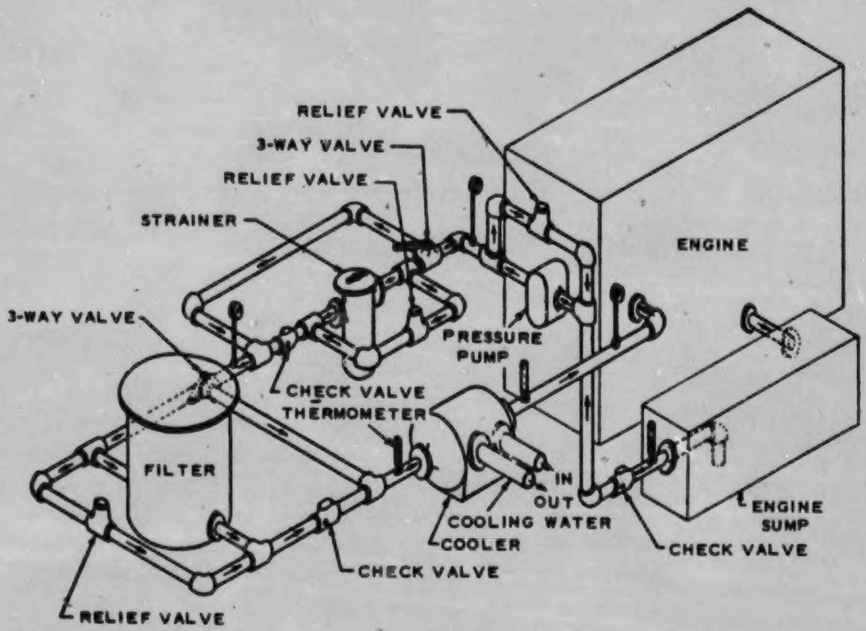


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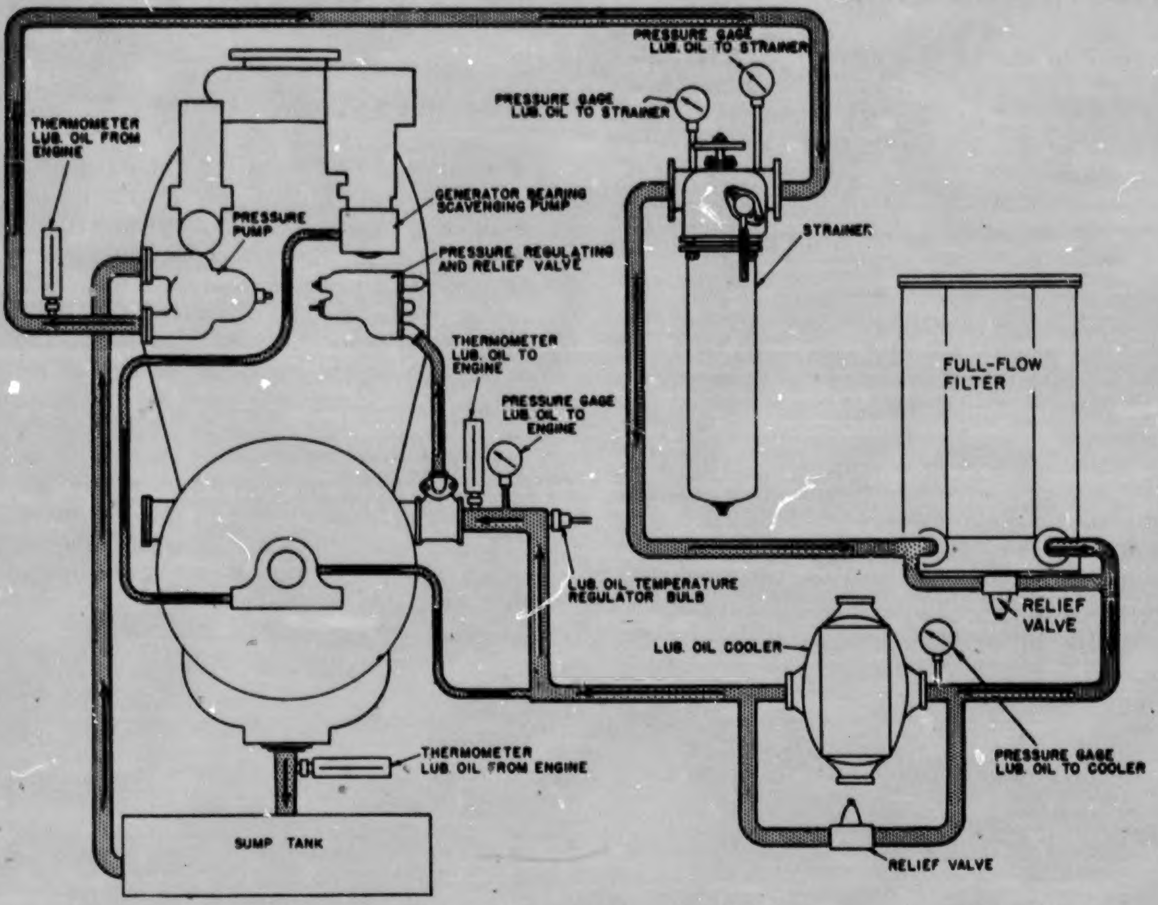
Figure 9-16.—Shunt-type lubricating oil filtering system.


PRESSURE GAGE
LUB. OIL TO STRAINER
PRESSURE GAGE
LUB. OIL TO STRAINER
THERMOMETER
LUB. OIL FROM
ENGINE
GENERATOR BEARING
SCAVENGING PUMP
PRESSURE
PUMP
STRAINER
PRESSURE REGULATING
AND RELIEF VALVE
THERMOMETER
LUB. OIL TO
ENGINE
FULL-FLOW
FILTER
PRESSURE GAGE
LUB. OIL TO
ENGINE
LUB. OIL TEMPERATURE
REGULATOR BULB
RELIEF
VALVE
LUB. OIL COOLER
THERMOMETER
LUB. OIL FROM ENGINE
PRESSURE GAGE
LUB. OIL TO COOLER
SUMP TANK
RELIEF VALVE

75.197X

Figure 9-17.—Full-flow lubricating oil filtering system.

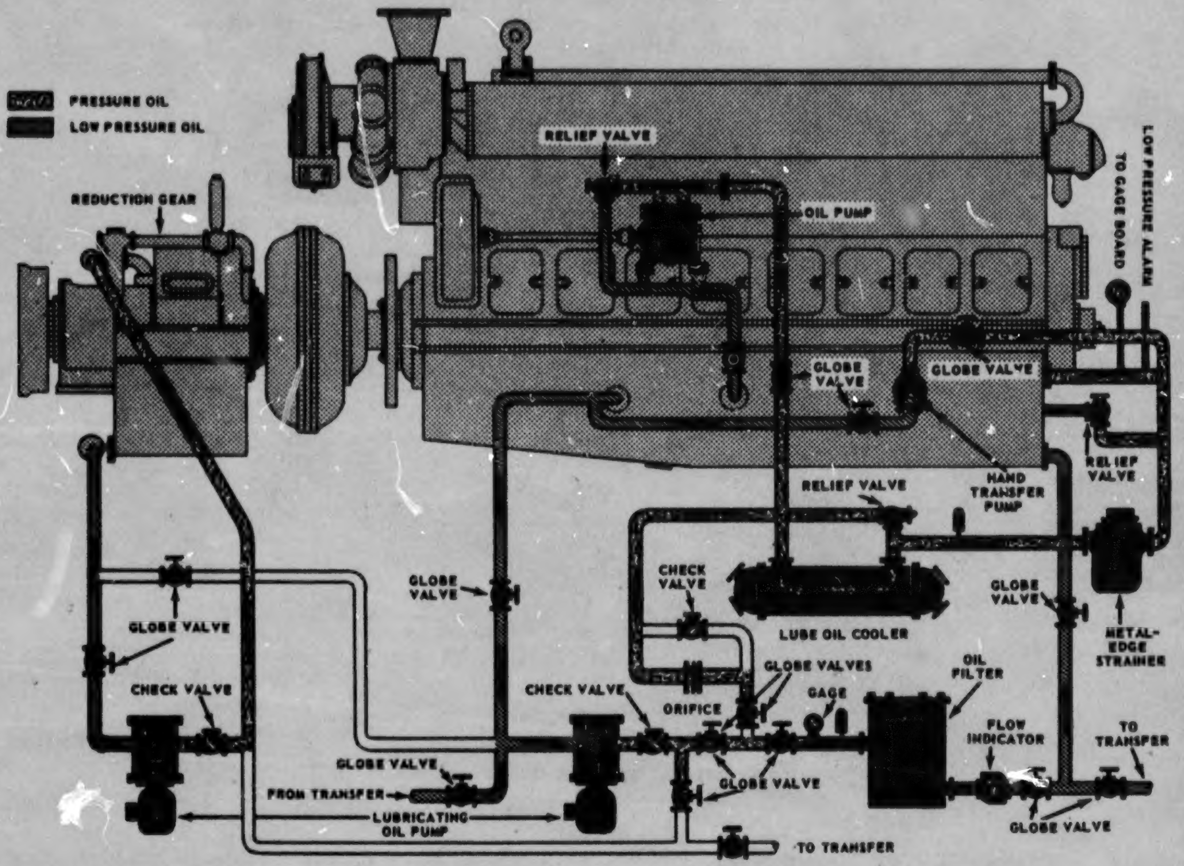
With the strainer located after the cooler, dirt from the cooler cannot enter the engine.

SUMP-FILTERING SYSTEM

The sump-filtering system is similar to the shunt system except that the filter is placed in a separate recirculating system which includes a separate motor-driven pump. The sump system permits the lubricating oil to circulate through the filter even when the engine is secured. In the sump-type filtering system, the motor-driven pump takes the oil to be filtered from the sump, forces it through the filter, and then discharges it back into the sump. Oil to the engine is taken from the sump by the engine-driven pump and forced through the cooler and strainer to the engine. The path of the oil through a sump-type filtering system is shown in figure 9-18.

BYPASS FILTERING SYSTEM

In many respects, a bypass filtering system is similar to a shunt system. The primary exception is that a portion of the oil discharged by the pressure pump in the bypass system is continuously bypassed back into the sump, through the filter or filters. To ensure that


PRESSURE OIL
LOW PRESSURE OIL
RELIEF VALVE
REDUCTION GEAR
OIL PUMP
LOW PRESSURE ALARM
TO GAGE BOARD
GLOBE VALVE
GLOBE VALVE
RELIEF VALVE
HAND TRANSFER PUMP
RELIEF VALVE
CHECK VALVE
GLOBE VALVE
GLOBE VALVE
LUBE OIL COOLER
METAL-EDGE STRAINER
GLOBE VALVE
GLOBE VALVES
OIL FILTER
CHECK VALVE
CHECK VALVE
GAGE
ORIFICE
FLOW INDICATOR
TO TRANSFER
GLOBE VALVE
FROM TRANSFER
LUBRICATING OIL PUMP
GLOBE VALVE
GLOBE VALVE
TO TRANSFER

75.198

Figure 9-18.–Sump-type lubricating oil filtering system.

sufficient oil is supplied to the engine, the amount of oil that flows through the filter is limited by the size of the piping and, if necessary, by an orifice. A valve is provided so that the flow of oil to the filter may be stopped. The arrangement of a bypass filtering system for one type of engine is shown in figure 9-19.

PATH OF OIL THROUGH THE DIESEL ENGINE LUBRICATING OIL SYSTEM

The path of the oil through the system piping and through the components external to the engine for the four types of diesel installations has been illustrated in figures 9-16 and 9-19. You will note in these illustrations that the sequence of the components through which the oil flows is not always the same. In general, the parts of the oil system external to the engine are arranged according to the type of engine and the installation, and the path of oil through the external components is governed by the type of filtration system used.

The part of a lubricating oil system which is external to an engine is classified according to the type of filtering system used; the internal part of a lubricating oil system is classified as either a dry-sump type or a wet-sump type.

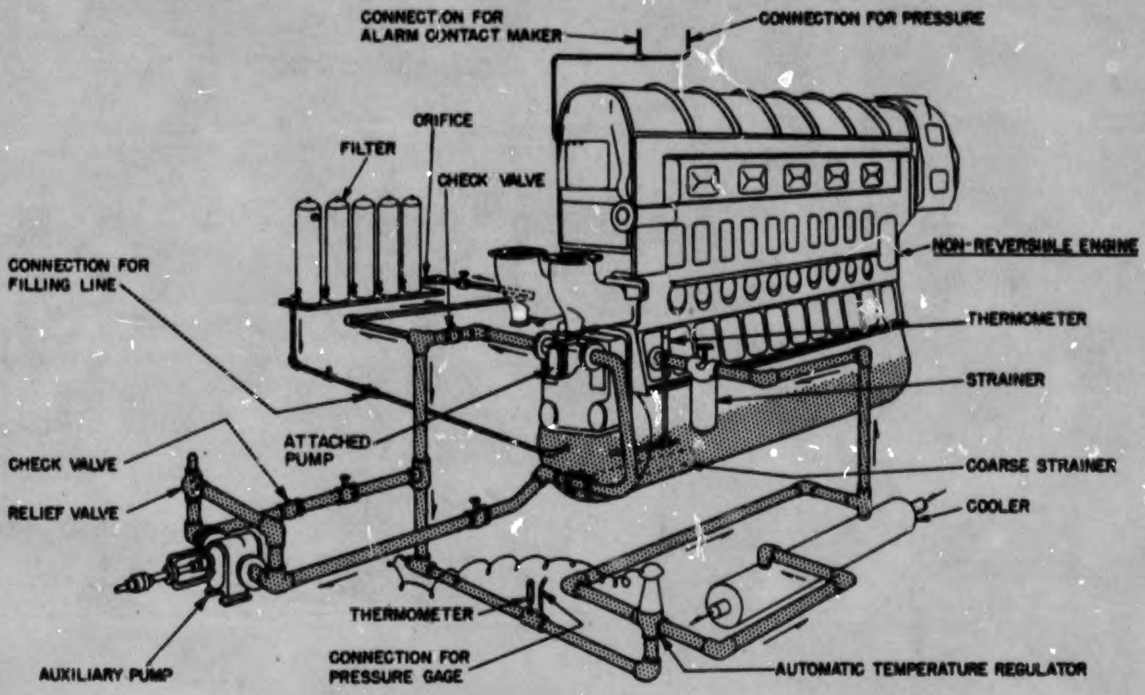

CONNECTION FOR ALARM CONTACT MAKER
CONNECTION FOR PRESSURE
ORIFICE
FILTER
CHECK VALVE
CONNECTION FOR FILLING LINE
NON-REVERSIBLE ENGINE
THERMOMETER
STRAINER
ATTACHED PUMP
CHECK VALVE
COARSE STRAINER
RELIEF VALVE
COOLER
THERMOMETER
AUXILIARY PUMP
CONNECTION FOR PRESSURE GAGE
AUTOMATIC TEMPERATURE REGULATOR

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Figure 9-19.—Bypass-type lubricating oil filtering system.

In the dry-sump type, the oil is returned by gravity to an oil pan, or sump. The oil is delivered continuously, by an engine-driven scavenging pump from the pan, or sump, to a separate sump tank, which may include the strainer and filter. The scavenging pump maintains the oil pan, or sump, nearly empty of oil; therefore, this system is known as the dry-sump system. Oil is drawn from the sump tank and recirculated through the engine by the pressure pump.

In the wet-sump system, the oil is returned to the oil pan, or sump, by gravity flow after it has lubricated the various parts of the engine. In systems of the wet type, the pressure pump draws oil directly from the oil pan, or sump, and recirculates the oil through the filtering equipment and the engine. The systems illustrated in figures 9-16 through 9-19 are of the wet-sump type. Note that these systems do not include a scavenging pump in the lubricating oil system.

Even though the design and arrangement of various diesel engine lubricating systems may appear different, the systems of most engines are similar in many respects. Some of the similarities and differences in lubricating oil systems have been pointed out in the preceding descriptions. Learning to trace the path of oil through the lubricating oil system of an engine will be easier if you refer to the illustrations shown in this chapter or in the applicable manufacturer's instruction manual.

VENTILATION OF INTERNAL SPACES

Most engines have some means to ventilate the internal cavities, or spaces, which are related to the lubricating oil system. Systems may be vented directly to the atmosphere or through

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the engine intake air system. The latter method is preferred in marine installations where the engine is located in an engineroom or other compartment. Venting the heated, fume-laden air directly to the atmosphere in a compartment will seriously contaminate the compartment air and may create a fire hazard. On the other hand, if the lubricating oil system is not vented in some manner, combustible gases may accumulate in the crankcase and oil pan. Under certain conditions, these gases may explode.

Under normal operating conditions, the mixture of oil vapor and air within an engine crankcase is not readily explosive. However, if a working part, such as a bearing or a piston, becomes overheated as a result of inadequate lubrication or clearances, additional oil will vaporize and an explosive mixture will be created. If the temperature of the overheated part is high enough to cause ignition or if a damaged part strikes another part and causes a spark, an EXPLOSION may occur.

In addition to the vapor created when lubricating oil contacts extremely hot surfaces, vapor may accumulate in the crankcase as a result of blowby past the pistons. Blowby occurs when the piston is compressing the air and during the power event.

There is little danger of a crankcase explosion or other troubles caused by vapors within the engine if the engine is kept in condition according to the prescribed maintenance program. The ventilation system of an engine greatly reduces the possibility of troubles which might occur because of an accumulation of vapors in the crankcase. Nevertheless, even when an engine is maintained according to prescribed procedures, casualties may occur, or conditions may be created which will lead to an explosion in the crankcase of the engine. When such casualties or conditions occur, they are generally due to abnormal operating circumstances or to the failure of a part.

You should be familiar with the possible causes of crankcase explosions so that you can learn how to prevent their occurrence. The importance of knowing what may cause a crankcase explosion and knowing the precautionary or preventive steps required are apparent when the aftereffects of an explosion are considered. A crankcase explosion may cause serious injury to personnel and extensive damage to the engine. Engineroom fires of a serious nature may occur after a crankcase explosion. Some of the mechanical defects which may lead to a crankcase explosion are crankshaft-bearing failure, damaged or excessively worn liners or piston rings, and cracked or seized pistons.

You may already be familiar with the preventive measures necessary to avoid some of the troubles which lead to the overheating or dilution of engine lubricating oil. Considerably more study and practical experience may be required on your part however before you learn how to prevent the conditions which lead to the overheating or dilution of lubricating oil.

OVERHEATED LUBRICATING OIL

The formation of explosive vapor from lubricating oil is greatly accelerated by a rise in the temperature of the lubricating oil. A rise in temperature may be due to such factors as insufficient circulation of the oil, inadequate cooling of the oil, a faulty temperature-regulating valve, overloading of the engine, or damaged or excessively worn parts. Immediate steps should be taken to correct overheated lubricating oil because, in addition to creating explosive vapors, it has other serious effects. The viscosity of the lubricating oil will be greatly reduced, and the tendency to form gum will be increased. The temperatures of the lubricating oil should be maintained at the value specified in the manufacturer's technical manual.

DILUTED LUBRICATING OIL

Dilution of engine lubricating oil with diesel fuel oil or JP-5 increases the tendency toward vapor formation in the crankcase because both of these fuels have lower flashpoints than lubricating oil. Petroleum products vary greatly in their flashpoints. (Flashpoint is the minimum temperature at which a product of petroleum gives off sufficient flammable vapors to ignite, or momentarily flash.) In general terms, gasolines give off sufficient vapor to ignite at temperatures well below freezing; diesel fuel oil will give off vapor in sufficient quantities to ignite when the oil is heated to approximately 140° F. On the other hand, a lubricating oil must be heated to a higher temperature (325° to 580° F, depending on the series and symbol of the oil) before it reaches its flashpoint. You should remember that dilution alone cannot cause a crankcase explosion. It may, however, contribute to making an explosion possible.

Dilution of engine lubricating oil may be caused by a variety of troubles. In general, dilution of the lubricating oil in diesel engines may result from worn or stuck rings, worn liners or pistons, fuel leaks, or leaky nozzles or injectors. You should also remember that, even though an engine is in good condition, dilution will occur during continuous engine operation at low speeds and under idling conditions. Under these conditions of operation, dilution occurs as a result of the blowby of unburned fuel particles which accumulate in the combustion spaces.

The effectiveness of the lubricating system depends on the quality of the lubricant and the good condition of the principal parts of the engine. The life of a diesel engine is remarkably long if it is effectively lubricated. Effective lubrication in turn depends on timely completion of required checks, inspections, and maintenance procedures.

CHAPTER 10

FUEL AND FUEL SYSTEMS

As an Engineman, you will be required to ensure that the proper types of fuels and lubricants are used in the machinery in your ship. The first section of this chapter deals with the common types of fuels and methods of testing them. The second section describes the hardware systems and components that store, transfer, and finally inject the fuel into the engine for burning.

ENGINE FUELS AND COMBUSTION

Except in an emergency, the fuels burned in the internal-combustion engines used by the Navy must meet the specifications prescribed by the Naval Sea Systems Command. Thus, the problem of selecting a fuel with the required properties is not your responsibility. Your primary responsibility is to follow the rules and regulations dealing with the proper use of fuels. You must strictly adhere to all prescribed safety precautions. You must also take every possible precaution to keep fuel as free as possible from impurities.

Fuels are generally delivered clean and free from impurities. However, the transfer and handling of fuel increase the danger of contamination with foreign material which interferes with engine performance. Sediment and water in fuel cause engine wear, gumming, and corrosion in the fuel system. Foreign material in fuel also causes an engine to operate erratically, with a power loss. For these reasons, periodic inspection, cleaning, and maintenance of fuel handling and filtering equipment are necessary.

Even though proper handling and use are your prime responsibilities with respect to fuel, knowing fuels and their characteristics will help you understand some of the problems in engine operation and maintenance.

GASOLINE

Gasoline for use as engine fuel must meet rigid requirements. It must vaporize readily and be capable of producing power without fuel knock. Gasoline must also be free of impurities which would interfere with the operation of the engine or the units of the fuel system. The ability of a liquid to change to vapor is known as VOLATILITY. All liquids tend to vaporize at atmospheric temperature, but their rates of vaporization vary. The rate of vaporization increases as the temperature increases and as the pressure decreases, temperature being the more important factor. In general, a highly volatile fuel will vaporize at atmospheric temperatures whereas high temperatures are required to vaporize a fuel of low volatility.

The volatility of gasoline affects engine starting, length of warmup period, and engine performance. You may better understand how engine operation is influenced by the volatility of the gasoline by considering how volatility influences starting and fuel distribution and how it may be the cause of vapor lock and crankcase dilution.

Gasoline must be in the form of vapor to properly combine with oxygen during combustion. This is the reason a highly volatile gasoline is desirable for engine starting since the volatility determines how much fuel will be vaporized in the fuel-air mixture. Generally, the proper fuel-air mixture consists of about 15 parts of air to 1 part of fuel, by weight. Even with this ratio, some of the vaporized fuel condenses and collects in the manifold when a "cold" engine is being started. Thus, more fuel must be added for starting and for operation until the engine reaches operating temperatures.

Proper distribution of fuel to the cylinders of a gasoline engine depends in part upon the fuel's being completely vaporized and mixed with air within the carburetor. Incomplete vaporization will result in an unequal distribution of the fuel-air mixture to the cylinders. When the fuel is not completely vaporized, engine operation will be "rough" and power output will decrease. Also, the unburned mixture will contribute highly to the pollution of air and water. A fully vaporized fuel mixture entering the combustion chambers is also essential for rapid and smooth acceleration of the engine.

If combustion is to be normal, the correct fuel must be used and the engine must be in proper operating condition. If either the fuel or the engine's operating condition is unsatisfactory, a portion of the fuel charge in a cylinder may explode instantaneously, instead of burning gradually. Loss of power and undesirable combustion noises are symptoms of such abnormal burning or uncontrolled combustion. The noises, or knocks, which result from abnormal combustion are generally referred to as FUEL KNOCKS, not engine knocks.

The antiknock characteristic of a gasoline is measured by its OCTANE VALUE. This value is expressed in terms of an "octane number." The octane number for a gasoline is determined by comparing the gasoline's performance with that of a fuel for which the octane value is known.

Two of the hydrocarbons in gasoline are iso-octane and normal heptane. Iso-octane has high antiknock qualities; normal heptane has low. For purposes of comparison, pure iso-octane is considered to have an octane value of 100 and normal heptane an octane value of zero. The performance of a gasoline of unknown octane value is compared with the performance of mixtures of normal heptane and iso-octane in a test engine, under specified test conditions. The proportions of iso-octane and normal heptane are varied until the mixture gives the same degree of knocking in the engine as the gasoline with the known octane value. The fuel with the unknown octane value is then given an octane rating number which represents the percentage of iso-octane in the hydrocarbon test mixture. For example, a gasoline with an 80-octane rating has knocking characteristics similar to those of a test mixture consisting of 80% pure iso-octane and 20% normal heptane.

Many of the gasoline engines used by the Navy burn an all-purpose fuel which is an 80-octane gasoline. Some high-speed, gasoline engines are designed to operate on fuel with not less than an 87-octane rating, while others require a 100-octane fuel for normal operation. In either type of engine, substitutes may be used without fuel-setting adjustments. When a fuel with a rating other than that specified for a particular engine is used, the prescribed limits on operating temperatures and pressures of the engine must not be exceeded.

With respect to octane rating, the tendency of a fuel to detonate varies in different engines and in the same engine under different operating conditions. The octane rating has nothing to do with starting qualities, potential energy, volatility, or other characteristics of a fuel. In general, the higher the octane value of a fuel, the less the fuel will knock. You must remember that each engine is designed to operate within a certain octane range. Performance will improve with the use of higher octane fuel within that range if the time of ignition is adjusted accordingly. However, if an engine operates satisfactorily at the upper limit of the octane rating range, the performance of the engine will not improve with use of a fuel with a higher octane rating unless the timing is advanced accordingly. If the ignition timing of an engine is advanced so that fuel with a higher octane rating can be used, it will be necessary to retard the timing to prevent excessive fuel knock when the use of fuel with the lower octane rating is resumed.

During the refining process, ANTIKNOCK COMPOUNDS are added to a gasoline to reduce its tendency to knock. Antiknock compounds reduce the rate of burning of the fuel during the final phase of combustion. These compounds also tend to prevent explosive burning or detonation. They raise the octane rating of a fuel artificially.

One of the most common antiknock compounds is tetraethyl lead. Since gasoline is supplied with the proper amount of lead or other knock inhibitor added, your primary responsibility is to use the fuel for the purposes intended. Gasoline which contains antiknock compounds should be used only for engine fuel. Regulations specify that "gasoline shall NOT be used for cleaning purposes under any circumstances." The need for such a regulation is obvious when the fire and toxic hazards of gasoline are considered. You are well aware of the explosive properties of a mixture of gasoline vapor and air. Regular gasoline has some toxic effect on the human system; however, a gasoline with a high octane rating has a greater poisonous effect because of the greater lead content. The lead compound vaporizes with the gasoline and may enter the body when the vapor is inhaled or may be absorbed through the skin. For your own safety, do NOT breathe air contaminated with gasoline vapors, and avoid contact with the liquid fuel. If any portion of your skin comes in contact with gasoline, wash the area with soap and water.

Lead-free gasoline is now produced for use in modern automobile engines with catalytic exhaust converters. This fuel uses various compounds other than lead to raise the octane rating. Again, NEVER use this gasoline for cleaning, and avoid contact with the skin.

DIESEL FUEL OIL

The fuel normally used in diesel engines is diesel fuel oil, but other fuels such as JP-5 and Navy distillate fuels are authorized for use in diesel engines where it is a logistic advantage. At present, most ships carry Navy distillate oil for boilers and for diesel engines.

When used in boilers, Navy distillate fuel burns more completely and cleaner, leaving fewer carbon deposits, than the Navy standard fuel oil formerly used. This not only helps reduce air pollution, but reduces the time spent cleaning burners and firesides and eliminates the need for carrying different types of fuel.

Because of the differences in the combustion processes and in the fuel systems of diesel and gasoline engines, the fuels for these engines must be refined to meet different requirements. In general, diesel engines require a particularly clean fuel; otherwise, the closely fitted parts of the injection equipment will wear rapidly and the small passages which create the fuel spray within the cylinders will become clogged. The diesel fuel oil must have a composition that permits it to be injected into the cylinders in a fine mist of fog. Diesel fuel oil must also have ignition qualities that permit the fuel to ignite properly and burn rapidly when it is injected into the cylinders.

The self-ignition point of a fuel is a function of temperature, pressure, and time. In a properly operating diesel engine the intake air is compressed to a high pressure (increases the temperature), and the injection of fuel starts a few degrees before the piston reaches TDC. The fuel is ignited by the heat of compression shortly after the fuel injection starts, and combustion continues throughout the injection period. Combustion is much slower than in a gasoline engine, and the rate of pressure rise is relatively small.

Immediately after injection, the fuel partially evaporates with a resultant chilling of the air in the immediate vicinity of each fuel particle. However, the extreme heat of compression rapidly heats the fuel particles to the self-ignition point and combustion begins. The fuel particles burn as they mix with the air. The smaller particles burn rapidly, but the larger particles take more time to ignite because heat

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must be transferred into them to bring them to the self-ignition point.

There is always some delay between the time fuel is injected and the time it reaches the self-ignition point. This delay is commonly referred to as IGNITION DELAY or "lag." The duration of the ignition delay is dependent upon the characteristics of the fuel, the temperature and pressure of the compressed air in the combustion space, the average size of the fuel particles, and the amount of turbulence present in the space. As combustion progresses, the temperature and pressure within the space rise; therefore, the ignition delay of fuel particles injected late in the combustion process is less than in those injected earlier. In a diesel engine the delay period between the start of injection and the start of self-ignition is sometimes referred to as the first phase of combustion. The second phase of combustion is ignition of the fuel injected during the first phase and the spread of the flame through the combustion space, as injection continues. The resulting increases in temperature and pressure reduce the ignition lag for the fuel particles entering the combustion space during the remainder of the injection period.

Remember that only a portion of the fuel has been injected during the first and second phases. As the remainder of the fuel is injected, the third or final phase of combustion takes place. The increase in temperature and pressure during the second phase is sufficient to cause most of the remaining fuel particles to ignite with practically no delay in the third phase as they come from the injection equipment. The rapid burning during the final phase of combustion causes an additional, rapid increase in pressure, which is accompanied by a distinct and audible knock. Such a knock is characteristic of normal diesel operation, particularly at light loads.

The knock which occurs during the normal operation of a diesel engine should not be confused with "detonation." Generally, detonation in a diesel engine is an instantaneous explosion of a greater than normal quantity of fuel in the cylinder, instead of only a portion of the fuel charge (as in the gasoline engine). Whether combustion is normal or whether detonation occurs is determined by the amount of fuel which is ignited instantaneously. The greater the amount of fuel which ignites at one time, the greater the pressure rise and the more severe the knock.

Detonation in a diesel engine is generally caused by too much delay in ignition. The greater the delay, the greater the amount of fuel that accumulates in the cylinder before ignition. When the ignition point of the excess fuel is reached, all of this fuel ignites simultaneously, causing extremely high pressures in the cylinder and an undesirable knock. Thus, detonation in a diesel generally occurs at what is normally considered the start of the second phase of combustion, instead of during the final phase, as in a gasoline engine. Detonation in a diesel engine may occur when the engine is not warmed up sufficiently, when fuel injection valves permit excessive fuel to accumulate in the cylinder.

Even though diesel fuel must have the ability to resist detonation, it must ignite spontaneously at the proper time under the pressure and temperature conditions existing in the cylinder. The ease with which a diesel fuel oil will ignite and the manner in which it burns determine the ignition quality of the fuel. The ignition quality of a diesel fuel is determined by its cetane rating, or CETANE VALUE. The cetane value of a diesel fuel is a measure of the ease with which the fuel will ignite. The cetane rating of any given fuel is identified by its "cetane number." The higher the cetane number, the less lag there is between the time the fuel enters the cylinder and the time it begins to burn.

The cetane rating of a diesel fuel is determined similar to the way the octane value of gasoline is determined. However, the hydrocarbons used for the reference fuel are cetane and alpha-methyl-naphthaline. Cetane has an excellent ignition quality (100) and alpha-methyl-naphthaline has a very poor ignition (zero). The cetane rating of a fuel whose ignition quality is unknown can be determined by comparing its performance with that of a reference fuel. The cetane number represents the percentage of pure cetane in a reference fuel which will just match the ignition quality of the fuel being tested. A higher cetane number means a quicker burning of the fuel and a better fuel from the standpoint of ignition and combustion.

TURBULENCE AND COMBUSTION IN DIESEL ENGINES

In both gasoline and diesel engines, the fuel and air must be properly mixed to obtain efficient combustion. In a gasoline engine, mixing takes place outside of the cylinder (in the carburetor) and the proper mixture is forced into the cylinder to be compressed. In the diesel engine, however, fuel in the form of small particles is sprayed into the cylinder after the air has been compressed. If each particle of fuel is to be surrounded by sufficient air to burn it completely (that is, if proper air-fuel mixture is to be obtained), the air in the combustion space must be in motion. This air motion is called TURBULENCE.

Various means are used to create turbulence. Design of engine equipment and parts and, in some engines, a process called precombustion enter into the creation of proper turbulence within the cylinder of an engine.

METHODS OF CREATING TURBULENCE

Fuel is distributed in the cylinders of a diesel engine by injection nozzles which atomize the fuel and direct it to the desired portions of the combustion space. FUEL INJECTION creates some turbulence but not enough for efficient combustion.

In 2-stroke cycle engines, scavenging-air PORTS are designed and located so that the intake air enters the cylinder with a whirling or circular movement. The movement of the air continues through the compression event and aids in mixing the air and fuel when injection occurs.

While fuel injection and the ports in 2-stroke cycle engines aid in creating air movement, additional turbulence is created in most engines by special shapes in the COMBUSTION SPACE. These shapes may include the piston crown and that portion of the cylinder head which forms part of the main combustion space. In some engines, auxiliary combustion chambers are provided as part of the combustion space to aid in mixing the fuel and air.

Even though there are many types of combustion chambers, all are designed to produce one effect–to bring sufficient air in contact with the injected fuel particles to provide complete combustion at a constant rate. Combustion chambers may be broadly classified under four types: open, precombustion, turbulence, and divided chamber. The last three terms are more commonly used to identify auxiliary combustion chambers; they are associated with the process called precombustion.

An open combustion chamber is the simplest in form. The fuel is injected directly into the top of the combustion space. The piston crown and (in some designs) the cylinder head are shaped to cause a swirling motion of the air as the piston moves toward TDC during the compression event. There are no special chambers to aid in creating turbulence. Open combustion chambers require higher injection pressures and a greater degree of atomization than other types to obtain the same degree of turbulence and mixing.

PRECOMBUSTION AND TURBULENCE

Some diesel engines have an auxiliary space or chamber at or near the top of each main combustion space. These chambers receive all or part of the injection fuel and condition it for final combustion in the main combustion chamber of the cylinder. This conditioning, called precombustion, involves a partial burning of the fuel before it enters the main combustion space. Precombustion helps to create the turbulence needed to properly mix the fuel and air. Because of differences in designs, the manner in which precombustion aids in creating turbulence differs from one type of auxiliary combustion chamber to another. For this reason, we shall discuss three types of auxiliary chambers by their common names—precombustion chambers, turbulence chambers, and air or energy cells.

Look at figure 10-1 to see how the precombustion chamber creates turbulence. The precombustion chamber, spherical in shape, is located in the cylinder head directly over the center of the piston crown. The precombustion chamber is connected to the main combustion space of the cylinder by a multiple orifice called a burner. During the compression event, a relatively small volume of compression-heated air is forced through the burner into the precombustion chamber. Heat stored by the burner increases the temperature of the compressed air and facilitates initial ignition.

Fuel is atomized and sprayed into the hot air in the precombustion chamber (A in fig. 10-1) and combustion starts (B). Only a small part of the fuel is burned in the precombustion chamber because of the limited amount of oxygen. The fuel which does burn in the chamber creates enough heat and pressure to force the fuel, as injection continues, into the cylinder at great velocity (C). The velocity of the fuel entering the main combustion space and the shape of the piston crown help to create the necessary turbulence within the cylinder (D).

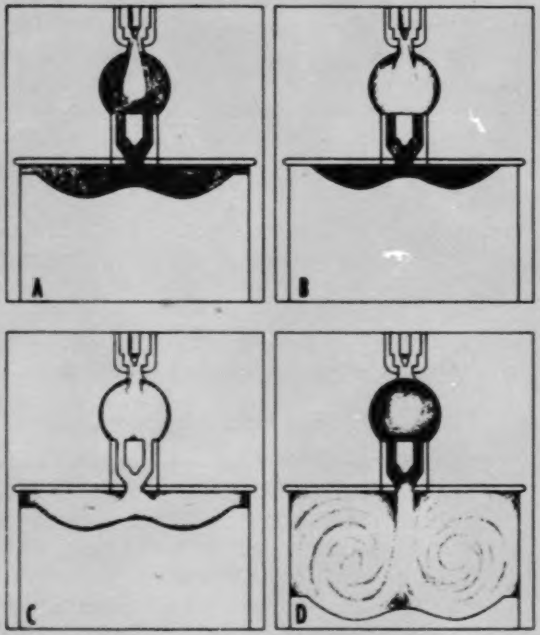

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Figure 10-1.—Precombustion chamber.

Engines that have precombustion chambers do not require fuel injection pressures as great as engines that have open type chambers. Also, the spray of injected fuel can be coarser, since the precombustion chamber functions to atomize the fuel further before it enters the cylinder.

Some engines have auxiliary combustion chambers. They differ mainly from precombustion chambers in that nearly all of the air supplied to the cylinder during the intake event is forced into the auxiliary chamber during the compression event. Auxiliary chambers in which this occurs are sometimes referred to as TURBULENCE CHAMBERS. There are several variations of turbulence chambers, one of which is illustrated in figure 10-2.

Note (in fig. 10-2) how turbulence, indicated by the arrows, is created in the auxiliary chamber as compression (A), injection (B), and combustion (C) take place. In engines with turbulence chambers there is very little clearance between the top of the piston and the head when the piston reaches TDC. (See B, fig. 10-2.) For this reason, a high percentage of the air in the cylinder is forced into the turbulence chamber during the compression event. The shape of the chamber (usually spherical) and the size of the opening through which the air must pass help to create turbulence. The opening to the turbulence chamber becomes smaller as the piston reaches TDC, thereby increasing the velocity of the air. Velocity plus deflection of the air as it enters the auxiliary chamber creates considerable turbulence. Fuel injection (see B of fig. 10-2) is timed to occur when the turbulence in the chamber is the greatest. This ensures a thorough mixing of the air and fuel. The greater part of combustion takes place within the

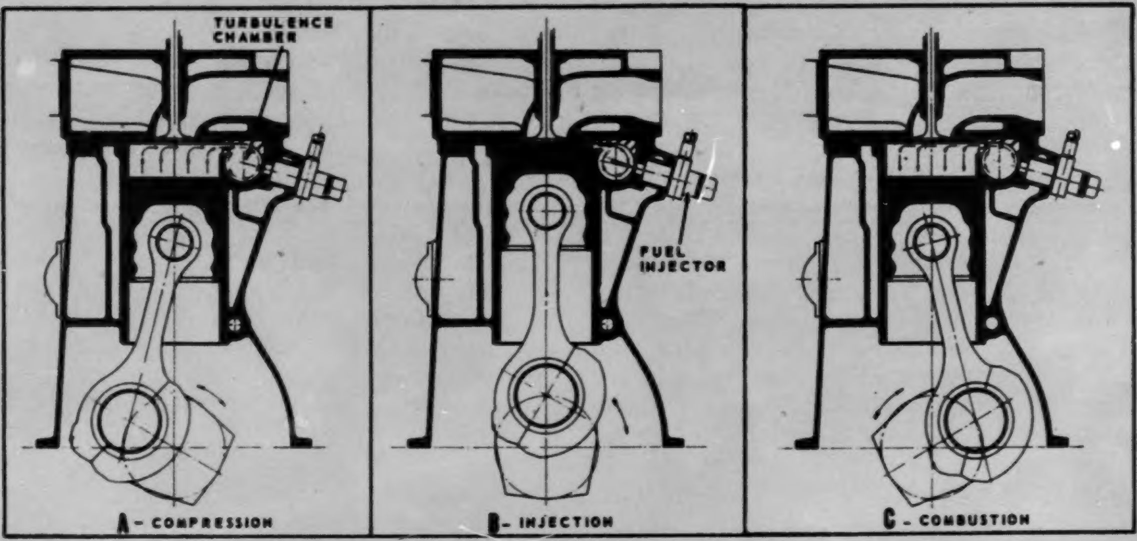
TURBULENCE CHAMBER
FUEL INJECTOR
A - COMPRESSION
B - INJECTION
C - COMBUSTION

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Figure 10-2.–Turbulence chamber.

turbulence chamber and is completed as the burning gases expand and force the piston down in the power event.

In some high-speed diesel engines, turbulence is created by an auxiliary chamber referred to as an ENERGY (AIR) CELL. Energy cells differ in design and location. In most engines, the cells are located in the cylinder heads. One type of energy cell which is located in the cylinder head is a divided chamber and turbulence chamber. The Lanova combustion chamber with energy cell is the divided chamber type. Cross-sectional top and side views of a divided auxiliary combustion chamber are shown in figure 10-3.

The divided auxiliary combustion chamber illustrated in figure 10-3 consists of a main combustion chamber (turbulence chamber) shaped like a figure 8 and an energy cell (precombustion chamber) which includes two air chambers. The main combustion chamber is centrally located over the piston and provides a housing for the engine valves. The energy cell, consisting of the major and minor air chambers, is located to the side directly opposite the fuel

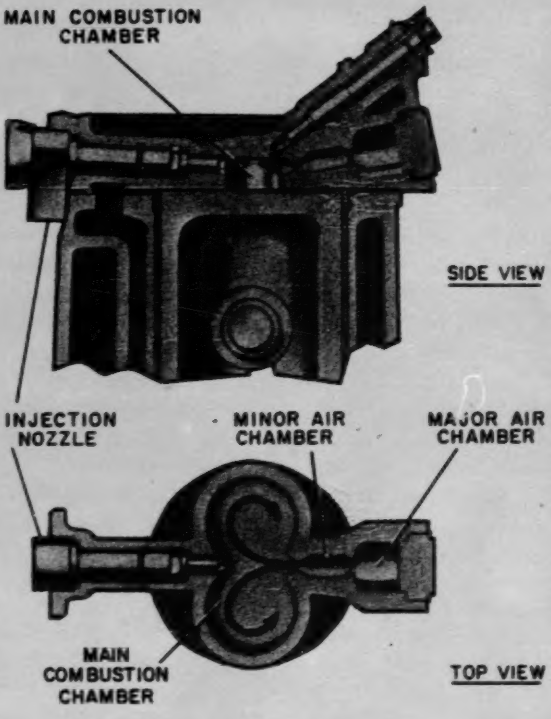
MAIN COMBUSTION CHAMBER
SIDE VIEW
INJECTION NOZZLE
MINOR AIR CHAMBER
MAJOR AIR CHAMBER
MAIN COMBUSTION CHAMBER
TOP VIEW

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Figure 10-3.–Divided combustion chamber.

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injection nozzle. The inner, or minor, air chamber of the energy cell is connected to the main combustion chamber and to the larger, or major, chamber of the cell by funnel-shaped passages.

The air charge is forced into the main combustion chamber during the compression event with a relatively small amount entering the energy cell at high velocity. Most of the fuel remains in the minor air chamber. However, enough fuel enters the major air chamber (where a sufficient quantity of compression-heated air is available) to create a spontaneous combustion of the mixture of fuel and air. Combustion in the major air chamber produces an extremely rapid rise in pressure which forces the fuel in the minor air cell back into the main combustion chamber. Because of the shape of the main combustion chamber, an exceedingly high rate of turbulence is created; thus causing a highly efficient mixing of unburned fuel with the air in the main combustion chamber. Combustion in the main chamber is relatively smooth and continuous compared to the spontaneous nature of the combustion in the energy cell. The restrictions in the connecting passages of the air chambers control the flow of fuel back into the main chamber so that combustion is prolonged, rather than sudden. Therefore, the rate of pressure rise on the piston is gradual, resulting in smooth engine operation.

The divided combustion chamber is similar, in some respects, to other types of chambers. It is similar to an open combustion chamber in that the main volume of air remains in the main combustion chamber and principal combustion takes place there. Both the divided chamber and the turbulence chamber depend on a high degree of turbulence to ensure thorough mixing and distribution of the fuel and air. However, turbulence in a divided combustion chamber is dependent on thermal expansion caused by combustion in the energy cell and not on engine speed as in other types of auxiliary combustion chambers.

FUEL SYSTEMS

In this section we shall deal with diesel engine fuel systems. Fuel systems are divided into two groups: external fuel systems and fuel injection systems.

The external fuel system stores and delivers clean fuel to the fuel injection system. In delivering fuel to the cylinders, the fuel injection system must fulfill the following requirements:

1. Meter or measure the correct quantity of fuel injected
2. Time the fuel injection
3. Control the rate of fuel injection
4. Atomize or break up the fuel into fine particles according to the type of combustion chamber
5. Pressurize and distribute the fuel to be injected

The ideal condition in the combustion space is to create a homogeneous mixture of the smallest possible fuel particles and air in the correct proportions. Although it is not possible to achieve an ideal condition, a good fuel injection system will come close.

METERING OF FUEL INJECTION

Accurate metering or measuring of the fuel means that for the same fuel control setting the same quantity of fuel must be delivered to each cylinder for each power stroke of the engine. Only with accurate metering can the engine operate at uniform speed with a uniform power output. Smooth engine operation and an even distribution of the load between the cylinders are dependent (1) on the same volume of fuel being admitted to a particular cylinder each time it fires and (2) on equal volumes of fuel being delivered to all cylinders of the engine.

TIMING OF FUEL INJECTION

In addition to measuring the amount of fuel injected, the system must properly time the injection to ensure efficient combustion so that maximum energy can be obtained from the fuel. When fuel is injected too early into the injection cycle, it may cause the engine to detonate and lose power, and have low exhaust temperatures. If the fuel is injected late into the injection cycle, it will cause the engine to have high exhaust temperatures, smoky exhaust, and a loss of power. In both situations, fuel economy will be low and fuel consumption will be high.

RATE OF FUEL INJECTION

A fuel system must also control the rate of injection. The rate at which fuel is injected determines the rate of combustion. The rate of injection at the start should be low enough that excessive fuel does not accumulate in the cylinder during the initial ignition delay (before combustion begins). Injection should proceed at such a rate that the rise in combustion pressure is not excessive; yet the rate of injection must allow fuel to be introduced as rapidly as possible to obtain complete combustion. An incorrect rate of injection will affect engine operation in the same way as improper timing. If the rate of injection is too high, the results will be similar to those caused by an excessively early injection; if the rate is too low, the results will be similar to those caused by an excessively late injection.

ATOMIZATION OF FUEL

As used in connection with fuel injection, atomization means the breaking up of the fuel, as it enters the cylinder, into small particles which form a mist-like spray. Atomization of the fuel must meet the requirements of the combustion chamber. Some chambers require very fine atomization, others can function with coarser atomization. Proper atomization assists the starting of the burning process and ensures that each minute particle of fuel will be surrounded by particles of oxygen with which it can combine.

Atomization is generally obtained when the liquid fuel under high pressure passes through the small opening(s) in the injector or nozzle. The fuel enters the combustion space at high velocity because the pressure in the cylinder is lower than the fuel pressure. The friction, resulting from the fuel passing through the air at high velocity, causes the fuel to break up into small particles.

PRESSURIZING AND DISTRIBUTION OF FUEL

Before injection can be effective, the fuel pressure must be sufficiently higher than that of the combustion chamber to overcome the compression pressure. The high pressure also ensures penetration and distribution of the fuel in the combustion chamber. Proper dispersion is essential if the fuel is to mix thoroughly with the air and to burn efficiently. While pressure is a prime contributing factor, the dispersion of the fuel is influenced in part by atomization and penetration of the fuel. (Penetration is the distance through which the fuel particles are carried by the kinetic energy imparted to them as they leave the injector or nozzle. Friction between the fuel and the air in the combustion space absorbs this energy.)

If the atomization process reduces the size of the fuel particles too much, they will lack penetration. Insufficient penetration results in ignition of the small particles of fuel before they have been properly distributed or dispersed in the combustion space. Since penetration and atomization tend to oppose each other, a degree of compromise in each is necessary in the design of fuel injection equipment, particularly if uniform distribution of fuel within the combustion chamber is to be obtained. The pressure required for efficient injection and, in turn, proper dispersion is dependent on the compression pressure in the cylinder, the size of the opening through which the fuel enters the combustion space, the shape of the combustion space, and the amount of turbulence created in the combustion space.

To control an engine means to keep it running at a desired speed either in accordance with or regardless of the changes in the load carried by the engine. The degree of control required depends on two factors: the engine's performance characteristics and the type of load which it drives.

In diesel engines, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder during each intake event. The amount of fuel injected into the cylinders controls combustion and thus determines the speed and power output of a diesel engine. A governor is provided to regulate the flow of fuel.

Other devices, either integral with the governor or mounted separately on the engine, are used to control overspeed or overload.

EXTERNAL FUEL SYSTEM

The fuel oil system in a diesel-powered naval vessel must be installed, operated, and maintained with the same care and supervision as the ship's engines. Inspections, maintenance, and operation of fuel oil tanks and fuel-handling equipment must be carried out in accordance with U.S. Navy Regulations and the manuals of the various bureaus concerned.

The fuel is pumped from the storage tank to the supply or day tank, and from there it is delivered to the fuel injection pumps on the engine. It is good practice to clean the fuel of sediment and water before it enters the supply tank. This is usually done with a centrifugal purifier. The fuel is transferred from the supply tank by an engine-driven pump (also called booster, transfer, or primary pump) through a metal-edge strainer and a cartridge-type, replaceable element filter to a header on the suction side of the fuel injection pumps. Excess fuel pumped to the fuel header and from the fuel injection pumps is returned to the supply tank.

The centrifugal purifier is a machine similar to the separator used for separating cream from milk. The oil enters a revolving bowl which tends to throw any heavy, solid contaminants to the outside of the bowl, followed by an intermediate layer of water which is heavier than the oil but lighter than the solids, and finally a central core of oil. The discharge holes in the top of the bowl are so located that the water can be drawn off separately from the fuel oil. (Note: Water in the fuel oil will probably cause the injection system to fail.) The solid material collects around the outer area of the bowl and must be cleaned out periodically. This cleaning should be done once a day unless idleness of engine or exceptionally clean fuel permits more extended periods.

The supply or day tank is usually vented to the atmosphere and mounted at a high point in the fuel system to allow all air to escape. All fuel lines must be kept under a pressure greater than atmospheric. Also, excessive foaming or splashing of fuel oil in the tanks should be avoided so that the air will not become entrained with the fuel; the air interferes with proper operation of the injection pump.

The engine-driven fuel transfer pump is the positive-displacement type, usually with a built-in relief valve to ensure constant pressure to the injection system. The fuel strainer is located on the suction side of the transfer pump, and the filter is connected into the system on the discharge side of the pump. The pressure drop across these filters and strainers increases with time. For this reason, some systems have a relief valve in the line before the cartridge filter so that the bypassed oil can be returned directly to the supply tank. The relief valve ensures a more constant fuel supply pressure and also tends to vent entrained air from the suction side of the system.

The primary metal-edge fuel strainer used in Navy installations is a duplex type which is actually two complete strainers connected by suitable headers or piping. This arrangement allows either strainer to be completely cut out of the system for cleaning or repair while all of the oil flows through the other strainer. Figure 10-4 shows a typical metal-edge strainer. A magnified view of a portion of the element is shown in figure 10-5. The oil flows from the outside to the inside. In Navy-approved strainers, the spaces between the leaves, or ribbons, which act as oil passages are between 0.001 and 0.0025 inch. The pressure drop across these strainers must not exceed 1.5 psi, with an

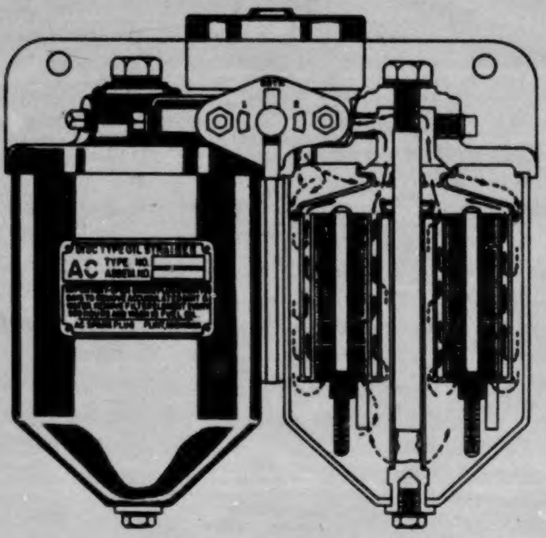

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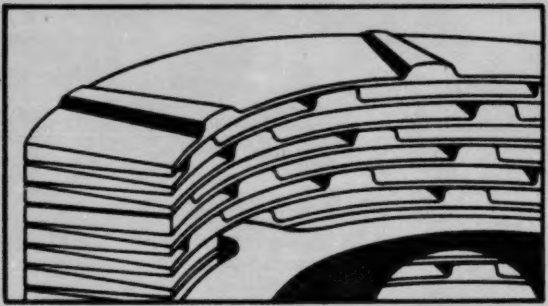
Figure 10-4.—Primary fuel strainer.



256.149
Figure 10-5.—Enlarged section of ribbon in strainer.

oil flow equal to the full capacity of the fuel oil pump. In some engines a duplex strainer is placed between the fuel supply tank and the transfer pump and, in operation, may be working under a vacuum.

The secondary, cartridge-type, fuel oil filter contains elements which are built to standard Navy dimensions. All new engine construction must incorporate such filter elements. The pressure drop across clean and new elements should not exceed 4.5 psi. The elements should be changed when the pressure drop reaches the value specified in the manufacturer's instruction book. The sump of the filters and strainers should be drained as often as practicable, preferably when the fuel is flowing.

FUEL INJECTION SYSTEM

Although there are several types of fuel injection systems in use, their functions are the same. The primary function of a fuel injection system is to deliver fuel to the cylinders at the proper time in the proper quantity, under various engine loads and speeds.

The fuel injection system may be the air injection type or the mechanical (solid) type. Since there are no air injection systems now in use, we shall limit our discussion to systems of the mechanical injection type.

Mechanical injection systems may be divided into three main groups: (1) common-rail, (2) individual pump or jerk type, and (3) distributor type. These types of systems may be further subdivided. The common-rail may be divided into the basic or original system and the modified common-rail system. The individual pump system may be divided into the original system, which has a separate pump and separate fuel injector nozzle for each cylinder in the engine, and the modified system, such as the General Motors type that has the injection pump and fuel nozzle in one unit, called the unit injector. The Roosa Master system, the Cummins PT system, and Bosch PSB series systems are examples of the distributor type system.

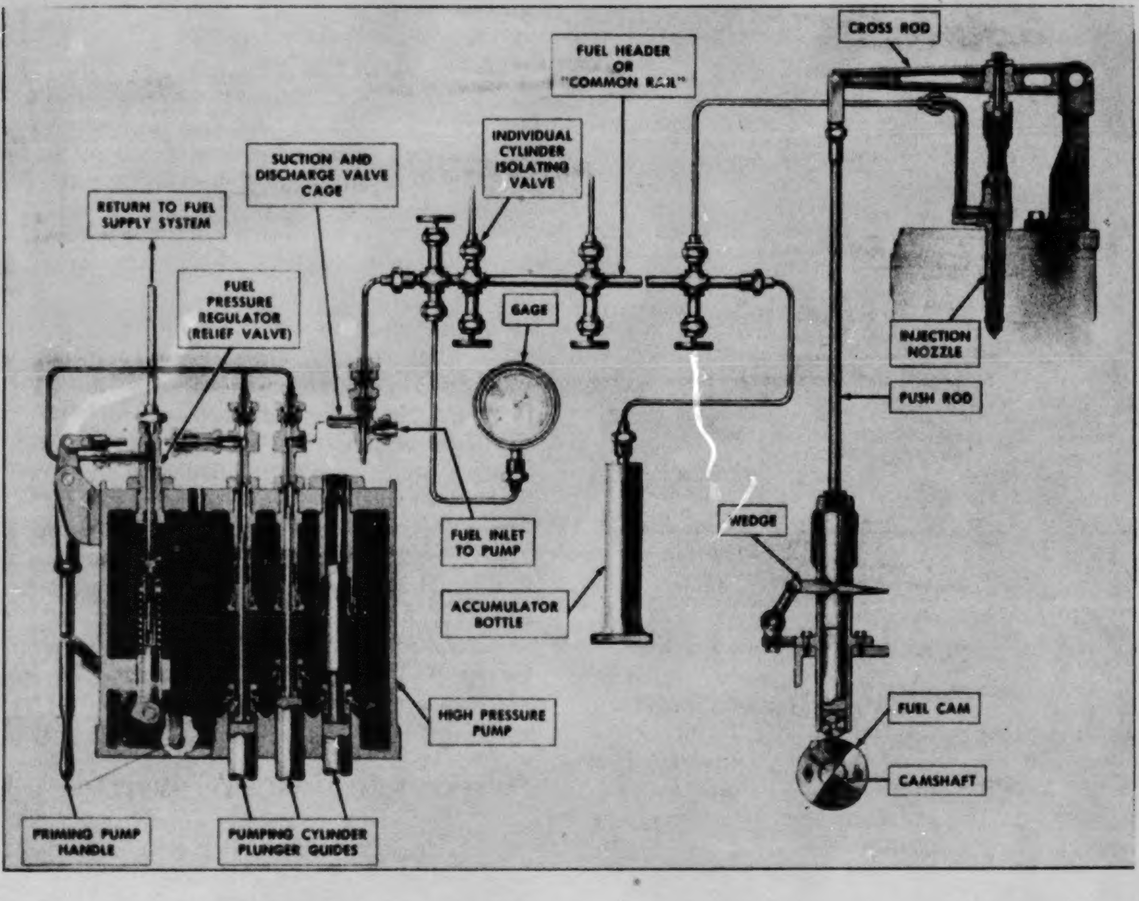
COMMON-RAIL INJECTION SYSTEM

The basic common-rail system consists of a high-pressure pump which discharges fuel into a common rail, or header, to which each fuel injector is connected by tubing. A spring-loaded bypass valve on the header maintains a constant pressure in the system, returning all excess fuel to the fuel supply tank. The fuel injectors are operated mechanically, and the amount of diesel fuel oil injected into the cylinder at each power stroke is controlled by the lift of the needle valve in the injector. The principal parts of a basic common-rail system are shown in figure 10-6.

MODIFIED COMMON-RAIL (CONTROLLED-PRESSURE) SYSTEM

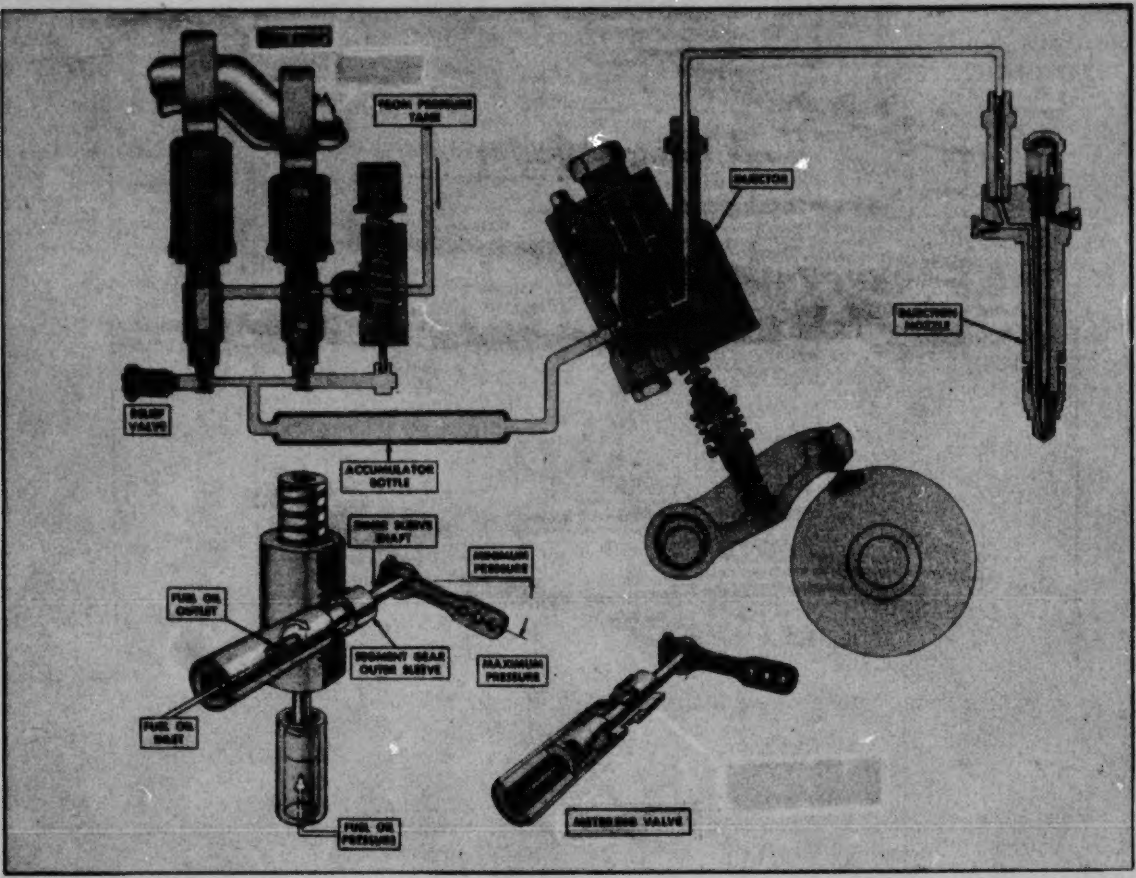
The modified common-rail system, sometimes called the controlled-pressure system, differs from the basic system in that the modified system has (1) mechanically operated fuel injectors and (2) the nozzles are operated hydraulically instead of mechanically. The nozzles of the modified system, shown in figure 10-7, do not meter the fuel; instead, (3) the fuel is metered by the injectors. In addition, (4) pressure is regulated by the high-pressure pump, instead of by a pressure regulator.

The pump plunger, on its downward stroke, first closes small holes that connect the pump barrel with the fuel admission line. Additional downward motion increases the oil pressure in the pump until it opens the spring-loaded discharge valve and delivers the oil into the


CROSS ROD
FUEL HEADER OR "COMMON RAIL"
INDIVIDUAL CYLINDER ISOLATING VALVE
SUCTION AND DISCHARGE VALVE CAGE
RETURN TO FUEL SUPPLY SYSTEM
FUEL PRESSURE REGULATOR (RELIEF VALVE)
GAGE
INJECTION NOZZLE
PUSH ROD
WEDGE
FUEL INLET TO PUMP
ACCUMULATOR BOTTLE
HIGH PRESSURE PUMP
FUEL CAM
CAMSHAFT
PRIMING PUMP HANDLE
PUMPING CYLINDER PLUNGER GUIDES

75.130

Figure 10-6.--Basic common-rail injection system.


FROM PRESSURE TANK
INJECTOR
INJECTION NOZZLE
RELIEF VALVE
ACCUMULATOR BOTTLE
INNER SLEEVE SHAFT
MINIMUM PRESSURE
FUEL OIL OUTLET
SEGMENT GEAR OUTER SLEEVE
MAXIMUM PRESSURE
FUEL OIL INLET
FUEL OIL PRESSURE
METERING VALVE

75.132

Figure 10-7.—Modified common-rail injection system.

injection system. During the return stroke, the spring moves the plunger upward, creating a vacuum. When the plunger uncovers the holes on top, oil from the suction side enters into the pump. The oil from the fuel oil pressure tank, on its way to the suction side of the pump, is admitted first to the inner side of a sleeve (sleeve valve). The inner and outer sleeves (fig. 10-7) have two mating holes. By turning the sleeves, one relative to the other and to the housing, the amount of fuel admitted to the pump is adjusted to meet the load and speed requirements. The outer sleeve is set and turned by the governor to admit enough fuel to correspond to the load carried by the engine. The inner sleeve is turned by a mechanism set to maintain a prescribed constant pressure in the system. If the pressure goes up, the sleeve is turned to decrease the effective area of the opening between the two sleeves. The amount of fuel taken by the pump is thus reduced and, as a result, the pressure in the system is decreased. On the other hand, when the pressure begins to drop, the sleeve is turned in the opposite direction to increase the effective area of the opening, more fuel goes into the pump, and the pressure goes up.

The injection nozzle consists of a spring-loaded plunger with a cone-shaped end

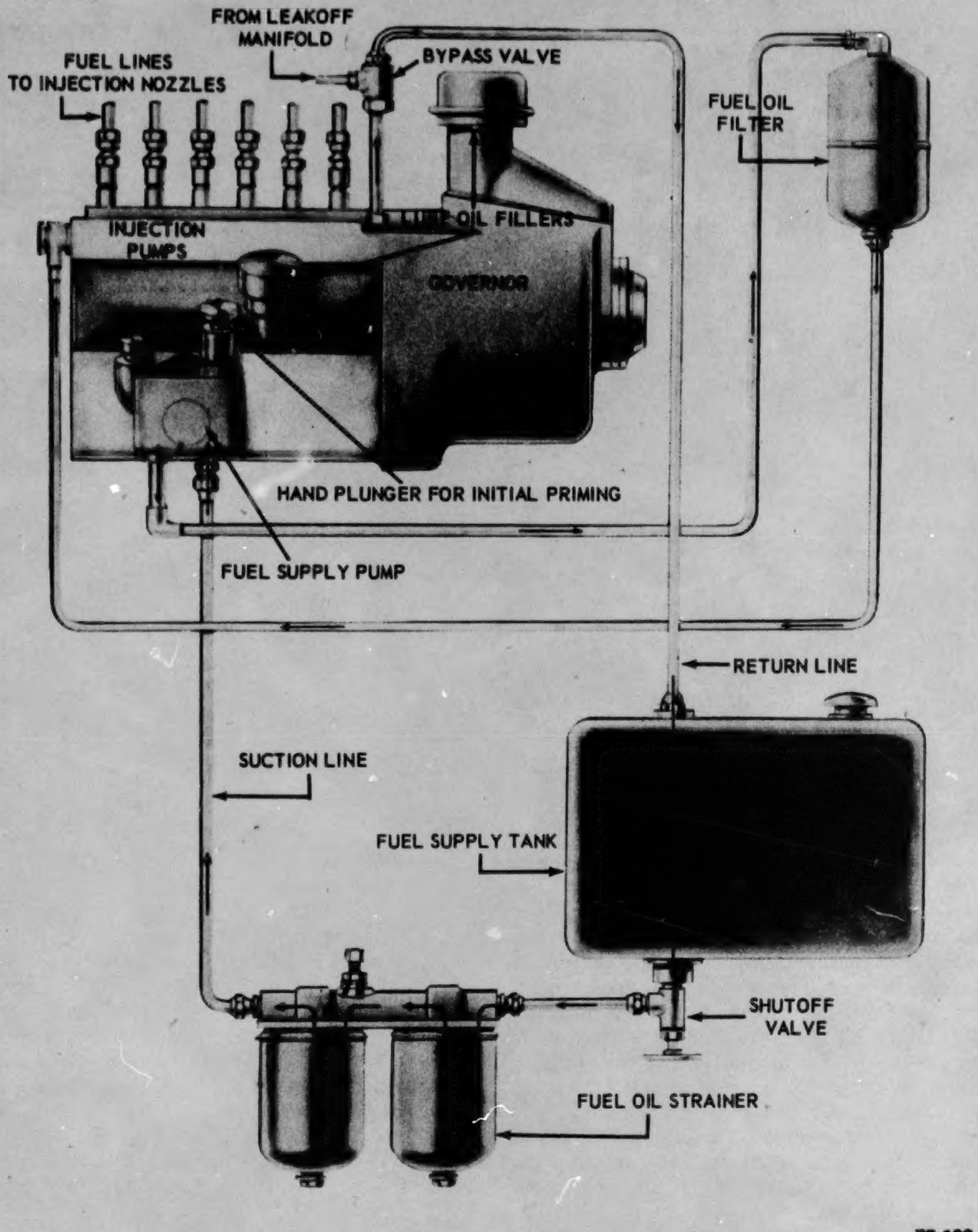

FROM LEAKOFF MANIFOLD
BYPASS VALVE
FUEL LINES TO INJECTION NOZZLES
FUEL OIL FILTER
INJECTION PUMPS
LUBE OIL FILLERS
GOVERNOR
HAND PLUNGER FOR INITIAL PRIMING
FUEL SUPPLY PUMP
RETURN LINE
SUCTION LINE
FUEL SUPPLY TANK
SHUTOFF VALVE
FUEL OIL STRAINER
75.133

Figure 10-8.—Fuel piping system with Bosch injection pump and governor.

which acts as a valve. When the injection nozzle valve is raised from its seat by the oil pressure, the valve is opened. When the oil pressure drops, the spring-loaded injection nozzle valve is returned to its seat, closing the valve. A quick closing of the injection nozzle and elimination of afterdribbling of the fuel into the combustion space is obtained as follows: the lifter plunger is drilled lengthwise at its center from the valve end to a point in line with the recess in the nozzle body (fig. 10-7). Another hole, drilled at a right angle to the central hole, connects with it, forming a passage from the lifter end to the recess and through it to the drain tank. The bottom of the injector valve is lapped to a seat with the end of the lifter plunger so that when the two are brought in contact during injection, the passage through the plunger is sealed. As soon as the fuel cam releases the lifter plunger, the valve is closed by its spring (fig. 10-7). The oil pressure on the end of the lifter plunger will move it downward, and a small amount of fuel oil will be spilled to the drain tank, relieving the oil pressure in the nozzle. The lifter spring will then return the lifter plunger to a contact with the valve. This arrangement is also a safety feature to prevent passage of the fuel oil into the engine cylinder, except when necessary, even if the injector valve should leak at its seat.

The advantage of the modified common-rail system over the basic common-rail system is that little effort is required to adjust the operating pressure. The modified system can be attached to the engine governor or throttle, so that the pressure automatically changes with load or speed. (In the basic system, the spring force of the pressure regulator must be adjusted manually.)

PUMP-INJECTION SYSTEMS

There are several pump-injection systems: individual pump injection systems, Bosch fuel systems, Roosa-Master fuel systems, Cummins PT fuel system, and unit injector systems.

INDIVIDUAL-PUMP INJECTION SYSTEMS

Individual-pump injection systems of the original jerk pump (basic) type include high-pressure pumps and pressure-operated spray valves or nozzles which are separate units. In some engines, there is only one pump and nozzle for each cylinder. In other engines, such as the Fairbanks Morse (FM 38C), each cylinder has two pumps and two nozzles.

Of all the individual-pump injection systems used by the Navy, the modified system is the most compact. A high-pressure pump and an injection nozzle for each cylinder are combined into one unit. This type of unit, generally used with General Motors (GM) engines, is often called a UNIT INJECTOR system.

In the following section we shall discuss the various pump-injection systems.

BOSCH FUEL SYSTEM

The Bosch fuel injection system is used on many of the Navy's diesel engines. Figure 10-8 illustrates the fuel piping of a Bosch fuel injection system and governor. A fuel supply pump, on the side of the injection pump housing, draws fuel from the supply tank and pumps it to the injection pumps through a duplex fuel oil strainer. The supply pump furnishes an excess of oil to the injection pumps; the excess oil is returned through a bypass valve and return line to the supply tank.

The fuel supply pump, mounted directly on the injection pump housing and driven by one of the cams on the injection pump camshaft, is a plunger-type pump which is self-regulating to build up to only a certain maximum pressure. Figure 10-9 is a phantom view of the Bosch fuel supply pump, showing the actual positions of the parts.

Bosch Fuel Injection Pumps

There are two basic designs of Bosch fuel injection pumps—type APE and type APF. Figure 10-10 illustrates the two types of injection pumps, together with high-pressure lines and spray nozzles.

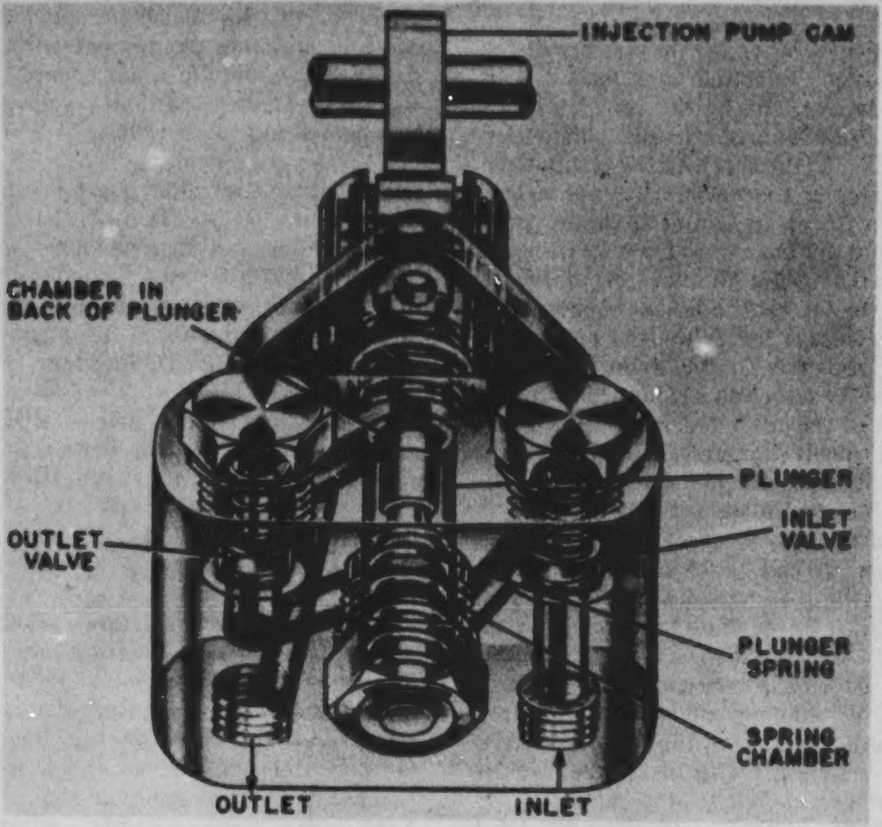


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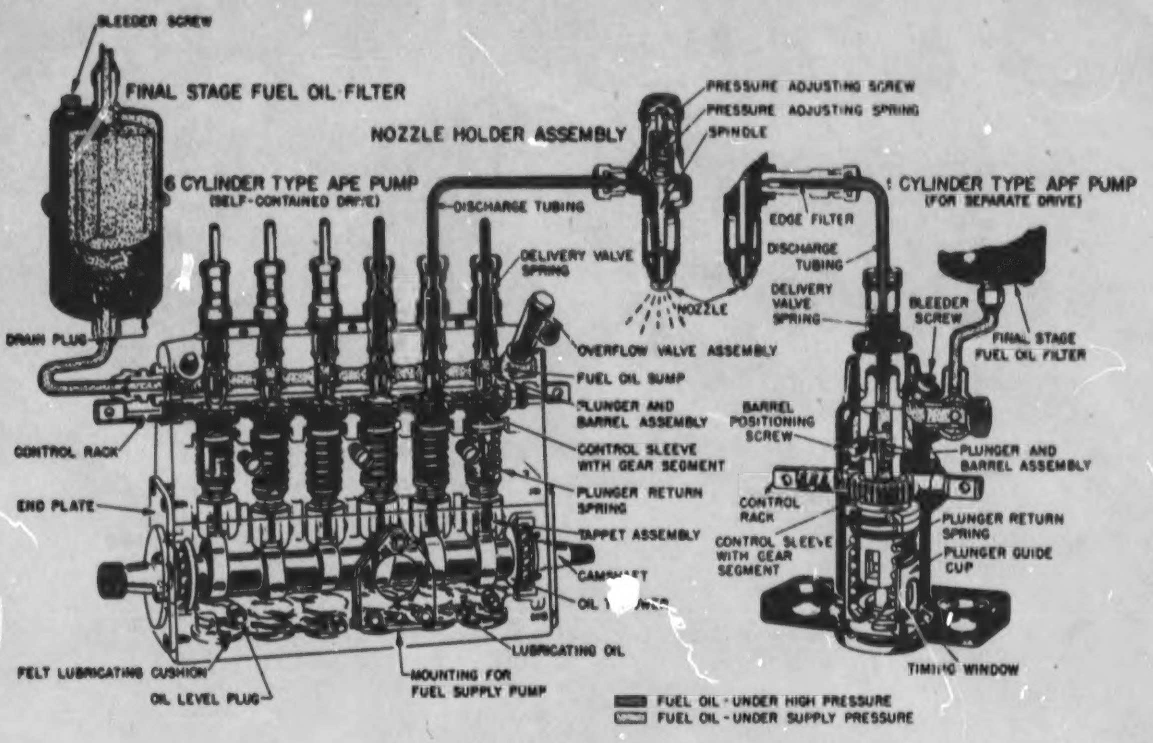
Figure 10-9.—Phantom view of Bosch fuel supply pump.

TYPE APF PUMP.—Type APF pumps are single-cylinder with the plunger pump for each cylinder in separate housing. In a 6-cylinder engine, for example, there are six separate APF pumps. Each pump is cam-driven and regulated by an individual control rack.

TYPE APE PUMP.—Type APE pumps are assembled with all the individual cylinder plungers in a single housing. The left side of figure 10-10 shows the pump assembly for a 6-cylinder engine. The injection pumps are operated from a single camshaft in the bottom part of the housing. The cams dip into lubricating oil and brush against felt cushions at the bottom of each revolution. At the top of each revolution, the cams force the spring-loaded plungers up against the plunger spring resistance.

Each plunger moves up and down in a barrel which contains fuel oil at the supply pressure. The plunger traps oil above it during part of the upward stroke and forces it through the delivery valve and high-pressure tubing to the spray nozzle, where it is injected into the combustion chamber. The action of the plunger, control rack, delivery valve, and spray nozzle are the same in both APE and APF types of pumps.

By studying figure 10-10, you will better understand the fuel injection mechanism and the


BLEEDER SCREW
FINAL STAGE FUEL OIL FILTER
NOZZLE HOLDER ASSEMBLY
6 CYLINDER TYPE APE PUMP
(SELF-CONTAINED DRIVE)
DISCHARGE TUBING
DELIVERY VALVE SPRING
NOZZLE
DRAIN PLUG
OVERFLOW VALVE ASSEMBLY
FUEL OIL SUMP
PLUNGER AND BARREL ASSEMBLY
CONTROL RACK
CONTROL SLEEVE WITH GEAR SEGMENT
END PLATE
PLUNGER RETURN SPRING
TAPPET ASSEMBLY
CAMSHAFT
OIL
LUBRICATING OIL
FELT LUBRICATING CUSHION
OIL LEVEL PLUG
MOUNTING FOR FUEL SUPPLY PUMP
PRESSURE ADJUSTING SCREW
PRESSURE ADJUSTING SPRING
SPINDLE
CYLINDER TYPE APF PUMP
(FOR SEPARATE DRIVE)
EDGE FILTER
DISCHARGE TUBING
DELIVERY VALVE SPRING
BLEEDER SCREW
FINAL STAGE FUEL OIL FILTER
BARREL POSITIONING SCREW
PLUNGER AND BARREL ASSEMBLY
CONTROL RACK
PLUNGER RETURN SPRING
CONTROL SLEEVE WITH GEAR SEGMENT
PLUNGER GUIDE CUP
TIMING WINDOW
FUEL OIL - UNDER HIGH PRESSURE
FUEL OIL - UNDER SUPPLY PRESSURE

75.136X

Figure 10-10.—Phantom views of APE and APF Bosch fuel injection pumps.

control of the amount of fuel injected. The fuel oil sump is filled with clean oil from the supply pump and fuel oil filter. Oil enters the barrel above the plunger through a pair of ports.

The amount of fuel forced out through the spray nozzle of each upward stroke of the plunger depends on how the plunger is rotated. In figure 10-10, notice that the control rack has teeth all along the side, meshing with a gear segment on each pump. Lengthwise movement of the control rack rotates all the plungers the same amount and in the same direction. Rotation of the plungers changes the part of the plunger helix that passes over the spill port (on the right side of each barrel in fig. 10-10), thus changing the time at which injection ends.

The pumping principle of the Bosch pump is illustrated by figure 10-11 which shows four steps of a pumping stroke. In part A the plunger is below the inlet and spill ports. Fuel oil enters the barrel (broken white arrow) and fills the barrel chamber (between the plunger and the delivery valve).

The plunger has a flat top, and the two ports are set at the same level. The two ports are closed by the plunger at exactly the same moment the plunger travels upward. In part B of figure 10-11 the ports have just closed. The fuel above the plunger is trapped and placed under high pressure by the rising plunger. The pressure forces the delivery valve up at once, allowing the high-pressure oil to go to the spray nozzle.

In part C of figure 10-11 the plunger is in the effective part of its stroke with both ports closed. Fuel is passing through the delivery valve to the spray nozzle. The effective stroke will

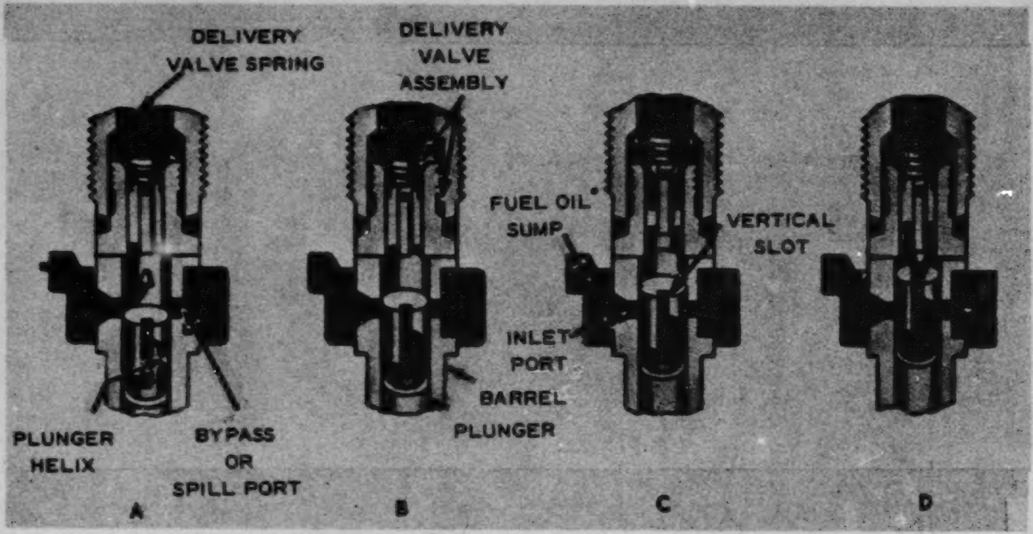


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Figure 10-11.—Upward stroke of Bosch plunger, showing pumping principle.

continue as long as both ports remain covered by the plunger.

At the moment the spill port is uncovered by the edge of the helix, as shown in part D of figure 10-11, fuel injection ends. As soon as the port is opened, the fuel oil above the plunger flows out through the vertical slot in the plunger and goes to the low-pressure fuel oil sump. The pressure above the plunger is released and the delivery valve is returned to its seat by the valve spring.

The effect of plunger rotation on fuel delivery is shown in figure 10-12A. In figure 10-12B the plunger is rotated to bring the vertical slot to the edge of the inlet port, which is the setting for maximum delivery. In this plunger position, the lowest part of the helix is in line with the spill port, allowing the longest possible effective stroke before the spill port is uncovered, ending the injection of fuel.

Figure 10-12C shows the setting for medium or normal delivery. This brings a higher part of the helix in line with the spill port and leaves a short effective stroke before the spill port is uncovered.

The position of "no fuel delivery" is reached when the plunger has been rotated to bring the vertical slot in line with the spill port (fig. 10-12A). In this plunger position, the fuel above the plunger will not be under compression during any part of the upward stroke.

The amount of fuel injected can be regulated by setting the plunger in any position between no delivery and maximum delivery. The plunger setting is controlled by the position of the control rack, which regulates all the plungers at the same time. Movement of the control rack, either manually or by governor action, rotates the plunger and varies the quantity of fuel delivered by the pump.

Figure 10-13 illustrates a cutaway view of the Bosch injection pump and control rack assembly. The gear segment is secured to the control sleeve, which is free to rotate on the stationary barrel. The control sleeve has a slot at the bottom into which fits the plunger flange.

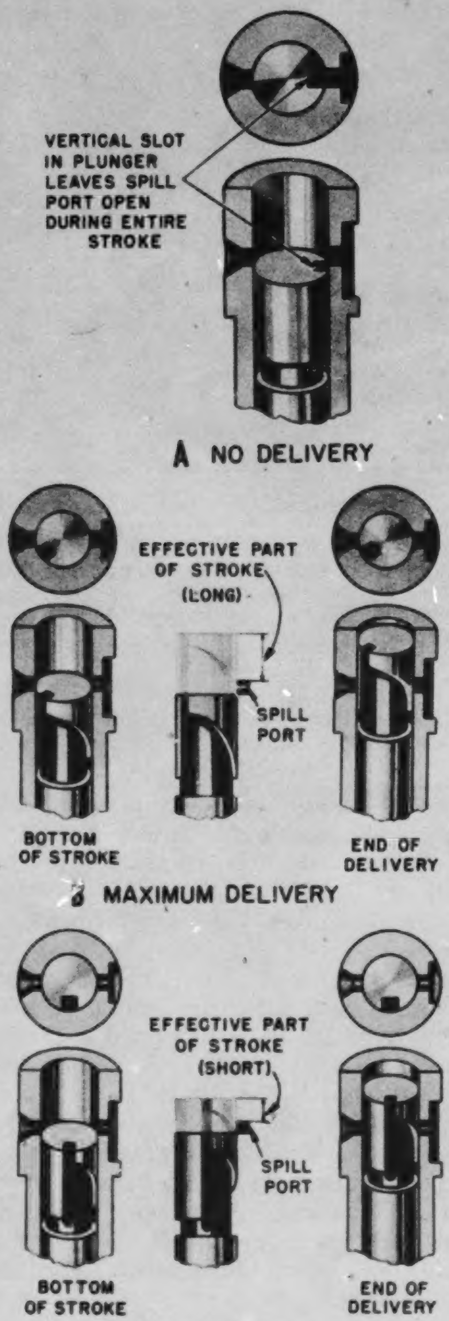
VERTICAL SLOT IN PLUNGER LEAVES SPILL PORT OPEN DURING ENTIRE STROKE
A NO DELIVERY
EFFECTIVE PART OF STROKE (LONG)
SPILL PORT
BOTTOM OF STROKE
END OF DELIVERY
B MAXIMUM DELIVERY
EFFECTIVE PART OF STROKE (SHORT)
SPILL PORT
BOTTOM OF STROKE
END OF DELIVERY
C MEDIUM DELIVERY

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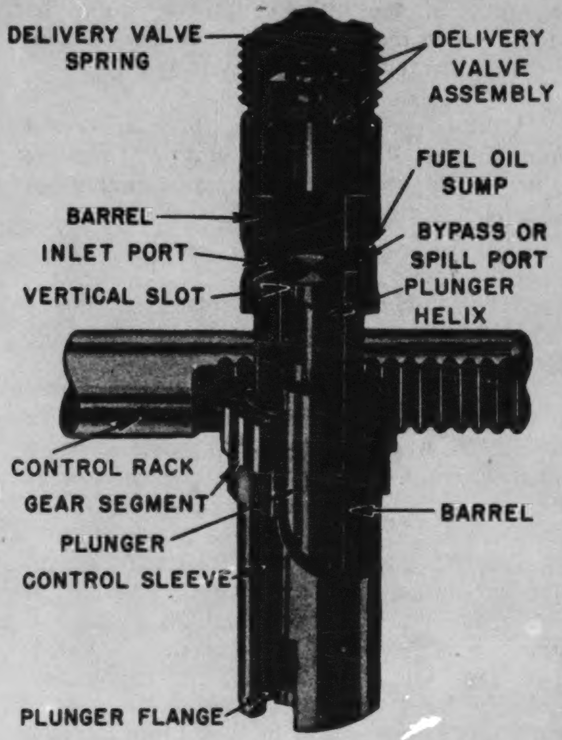
Figure 10-12.—Effect of plunger rotation on fuel delivery.


DELIVERY VALVE SPRING
DELIVERY VALVE ASSEMBLY
FUEL OIL SUMP
BARREL
INLET PORT
BYPASS OR SPILL PORT
VERTICAL SLOT
PLUNGER HELIX
CONTROL RACK
GEAR SEGMENT
BARREL
PLUNGER
CONTROL SLEEVE
PLUNGER FLANGE

75.139X

Figure 10-13.—Bosch injection pump and control rack assembly.

The flange moves in the slot as the plunger moves up and down. When the control rack is moved lengthwise, the gear segment and the control sleeve rotate around the outside of the barrel. The plunger flange and the plunger (inside the barrel) follow the rotation of the control sleeve.

The Bosch plunger, shown in figures 10-11, 10-12 and 10-13 has a flat top surface and only a lower helix. With this type of plunger, fuel injection will always begin at the same point in the piston cycle, whether it is set for light load or heavy load. Injection begins when the ports are closed; the end of injection can be varied by plunger rotation. This type of plunger is used in pumps marked "Timed for port closing." Injection has a constant beginning and variable ending.

Another type of Bosch plunger has only an upper helix. Rotation of the plunger varies the beginning of the effective stroke, while the ending is constant. This type of plunger is used in pumps marked "Timed for port opening."

A third type of plunger has both upper and lower helixes. Rotation of this type of plunger varies both the beginning and ending of injection.

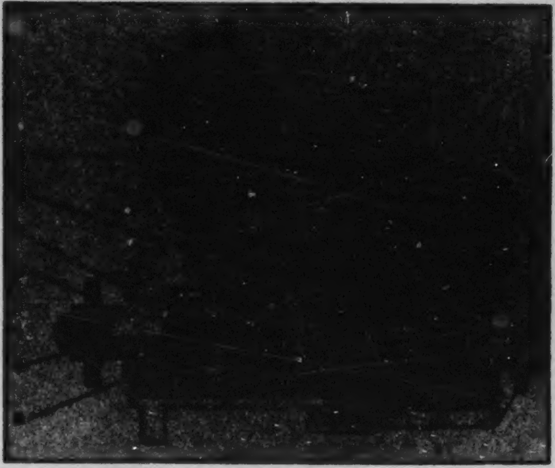
Bosch PSB Fuel Injection System

The Bosch PSB fuel injection system is used on diesel engines for small boats. It is similar to the Bosch APE fuel system in that it has a supply pump, governor, and high-pressure injection pumps built into a single assembly.

The PSB injection pump is a single-plunger, constant-stroke, six-outlet unit, driven at crankshaft speed, and actuated by a cam and tappet arrangement which also carries gearing for distribution function. Its replaceable hydraulic head contains a single delivery valve and a single plunger which, in addition to being reciprocated by the multilobe cam, is rotated continuously to serve as its own fuel distributor. Fuel discharge is varied by axial movement of the plunger control sleeve, similar to that used in most other pumps of this type, which is linked to the governor. The governor is mounted integrally with the injection pump.

A positive-displacement, gear-type fuel pump, mounted on the front side of the housing, is driven from the distributor drive gear on the pump camshaft. There is a hand priming pump for bleeding fuel lines, mounted either beside the injection pump or integrally with the fuel transfer pump.

The Bosch PSB single-plunger fuel pump functions the same as the multiplunger Bosch APE fuel pump used on earlier models. It meters the fuel accurately and delivers it under high pressure to the spray nozzles through which the fuel is injected into the engine cylinders at a definite timing in relation to the engine firing cycle and within the required injection period. The PSB pump simplifies servicing. It has substantially fewer parts than the APE pump.



A - ALUMINUM HOUSING
B - CAMSHAFT
C - SLEEVE BEARING
D - FRONT BALL BEARING
E - CAM
F - CAMSHAFT SPLINE
G - DRIVE HUB
H - SPIRAL GEAR
I - QUILL SHAFT
J - TAPPET GUIDE
K - ROLLER TAPPET
L - TAPPET PIN

75.320

Figure 10-14.—PSB pump housing and drive mechanism.

The PSB pump requires less mounting space than the APE fuel pump, because the PSB is much shorter and more compact. The PSB assembly has three main divisions: the housing with drive mechanism, the hydraulic head, and the governor.

The PSB injection pump housing, figure 10-14, has a camshaft compartment in the lower half. The camshaft (B) is supported at the rear by a sleeve bearing (C) and at the front by a ball bearing (D). The cam (E), just below the plunger assembly in the hydraulic head, has three lobes. The camshaft has a spline (F) at the forward end to receive the drive hub (G) and has a spiral gear (H) cut into it adjacent to the cams to mate with and drive the lower gear of the quill shaft (I) assembly of the distributing system. The same spiral gear also drives the fuel transfer pump which is attached to the front of the pump housing at this location. There is also a pointer at the drive end of the pump to align with a mark on the gear hub for an accurate setting of the injection timing.

The hydraulic head of the PSB pump, figure 10-15, is a complete assembly fastened to the housing by four studs. It is easily removed for service or replacement. The assembly consists of the head block, the lapped plunger, the control sleeve, the delivery valve assembly, and the plunger return springs.

The PSB governor, figure 10-16, whose weight assembly is attached to the fuel pump camshaft, is considered an integral part of the PSB pump assembly. The governor is the variable-speed, mechanical-centrifugal type. The governor action is accomplished through flyweight action against a movable sleeve which is backed by springs loaded in the opposite direction.

ROOSA-MASTER FUEL SYSTEM

The Roosa-Master fuel system is used on some Navy diesel engines such as the Gray Marine. This fuel system is somewhat similar to the Bosch APE and the Bosch PSB in that it also contains a supply pump, a governor, and a high-pressure injection pump built into one assembly. The difference is in the method of pumping and measuring fuel.

A - HEAD BLOCK
B - DISCHARGE
C - FUEL INLET
D - CONTROL SLEEVE
E - PLUNGER
F - PLUNGER DRIVE GEAR
G - PLUNGER GUIDE
H - LOWER SPRING SEAT
I - GEAR RETAINER
J - DELIVERY VALVE
K - VALVE SPRING
L - VALVE RETAINER
M - COPPER GASKET

75.321

Figure 10-15.—Hydraulic head, PSB pump.

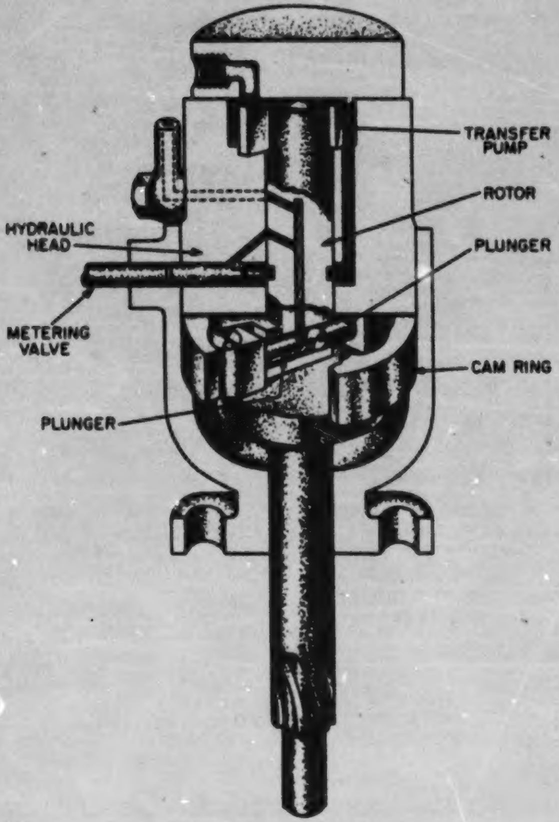
A - ALUMINUM HOUSING
B - WEIGHT SPIDER
C - WEIGHTS
D - SLIDING SLEEVE
E - THRUST BEARING
F - FULCRUM LEVER
G - CONTROL ROD EXTENSION
H - STOP PLATE
I - SMOKE LIMIT CAM
J - GOVERNOR SPRINGS
K - SPRING COVER
L - YOKE

75.322

Figure 10-16.—PSB governor.

The Roosa-Master assembly draws fuel from the supply tank and forces it through a filter and meters, distributes, and delivers the fuel at the proper time under high pressure to the injection nozzles. The assembly itself is oiltight, pressurized, and self-lubricated by the fuel oil it pumps. It is gear-driven from the camshaft. The assembly housing contains the pumping and metering elements plus the drive shaft and a hydraulic governor. The pumping and metering mechanism has five major parts, as shown in figure 10-17—the transfer pump, the hydraulic head, the rotor, the injection pump plungers, and the cam ring.

The transfer pump is a four-vane, positive-displacement pump which supplies fuel



75.305
Figure 10-17.—Roosa-Master injection pump.

to the metering device at an even and predetermined pressure. The shape of the pumping cavity has been modified from the usual crescent shape to provide an almost constant flow. A spring-loaded bypass valve controls the pressure.

The hydraulic head houses the metering mechanism and most of the oil passages. The metering valve is a closely fitted plunger moving in and out within its cylindrical barrel in the hydraulic head. The metering plunger accurately measures the fuel injected into each cylinder in response to governor action. The outlet connections to the injection nozzles are mounted on the hydraulic head.

The rotor is the major rotating assembly. It contains bored passages for fuel oil distribution. As the rotor turns, it causes different fuel oil passages to align with those in the hydraulic head so that fuel oil from the injection pump can be distributed at the proper time to the proper injection nozzle. The injection pump plungers are mounted in the drive end of the rotor. The upper end of the rotor drives the transfer pump.

The injection pump has two opposed plungers closely fitted in a bore perpendicular to the shaft axis. The plungers are actuated simultaneously by shoes and rollers bearing on the cam ring.

The cam ring is stationary and is mounted internally in the housing. As the entire rotor (including the plungers) turns in the hydraulic head, opposing internal lobes in the cam ring simultaneously force the injection pump plungers inward toward each other. This action exerts pressure on the fuel between the plungers and delivers the fuel at high pressure to the injection nozzles. As the rotor continues to turn, the rollers ride down the lobes of the cam ring, allowing the plungers to move outward away from each other. Thus another charge of fuel is forced into the pump cavity between the plungers. Note that the fuel can enter the pump cavity and then be discharged to the injection nozzles only at the proper time. The timing relationship is established by the position of the drilled passageways in the rotor and can never be altered by adjustment or improper assembly. There is always uniform fuel delivery to each injection nozzle.

CUMMINS PT FUEL SYSTEM

The Cummins PT fuel system is designed for use on all diesel engines manufactured by Cummins; it can be adapted, with some modifications, for all Cummins diesel engines now in use by the Navy. This fuel system is somewhat different from the fuel systems previously discussed.

The identifying letters PT are an abbreviation for "pressure time." The PT fuel

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system operates on the principle that a change in the pressure of a liquid flowing through a pipe will change the amount of liquid coming out the open end. Increasing the pressure increases the flow and decreasing the pressure decreases the flow.

The PT fuel system consists of a fuel pump assembly, supply and drain lines, and injectors. The system delivers fuel to each cylinder in equal and predetermined amounts.

The fuel pump assembly (fig. 10-18A) consists of five main units: a gear pump, a pressure regulator, a throttle, a governor, and a shutdown valve. The gear pump, consisting of a single set of gears, is driven by the camshaft gear and turns at camshaft speed. It draws fuel from the supply tank and delivers it to the injectors.

The pressure regulator can be referred to as a bypass valve; its primary function is to control fuel pressure at the gear pump. The pressure regulator controls and limits fuel pump pressure by the bypass method. Excess fuel is delivered back to the suction side of the pump, limiting fuel delivery to the required amount for any given speed or load.

The throttle and the governor are very closely related. All fuel for engine operation must pass through the throttle shaft before going to the governor. The specific function of the throttle varies somewhat, dependent on the type of governor installed. When the governor controls only the idling and the maximum speeds, the throttle controls the fuel oil flow to the injectors in the speed range between idling and maximum. When the governor is the variable-speed type, the governor itself controls the fuel oil flow to the injectors for any speed within the governor's range. With a variable-speed governor, the throttle acts only as a positive shutdown device.

The shutdown valve gives positive engine shutdown by cutting off completely the flow of fuel to the injectors. The shutdown valve can be operated either electrically or manually.

The Cummins PT injectors meter and inject fuel into the combustion chambers. Fuel circulates through the injectors at all times except during a short period after the completion of the injection cycle. The circulation of the fuel keeps fuel at the metering orifice at all times and reduces injector temperature. The fuel is metered when the metering orifice is opened by the injector plunger (fig. 10-18B). The injector plunger acts as a valve to open and close the metering orifice. As the injector plunger uncovers the metering orifice, fuel pressure forces fuel into the injector cup. Engine speed determines the length of time the fuel is metered into the injector cup.

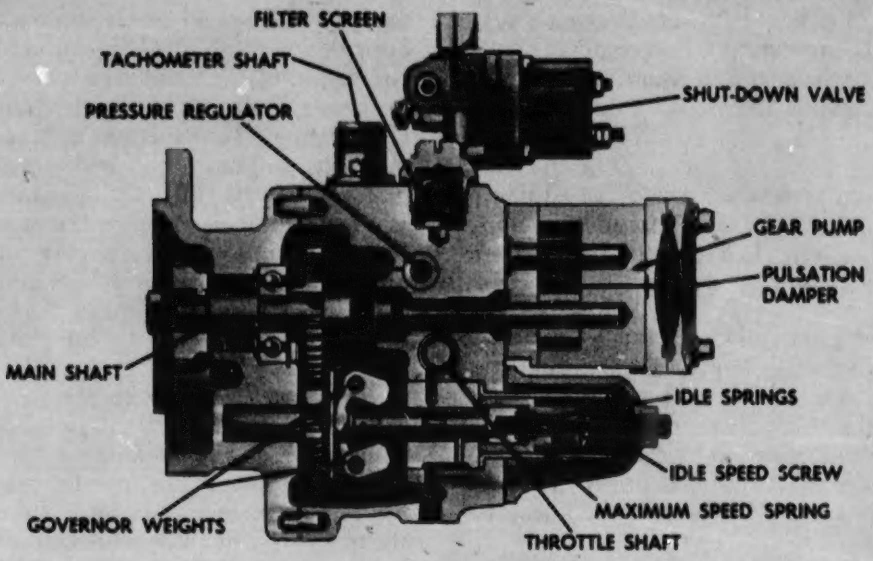
Injection begins when the piston nears the end of the compression stroke. The falling plunger closes the metering orifice and forces the fuel trapped in the injector cup out through the spray holes and into the combustion chamber. The injector plunger then remains in the injector cup seat throughout the power and exhaust events. The amount of fuel that is injected into the combustion chamber is regulated by both the time that the metering orifice remains open and the fuel pressure to the orifice.

UNIT INJECTOR SYSTEM

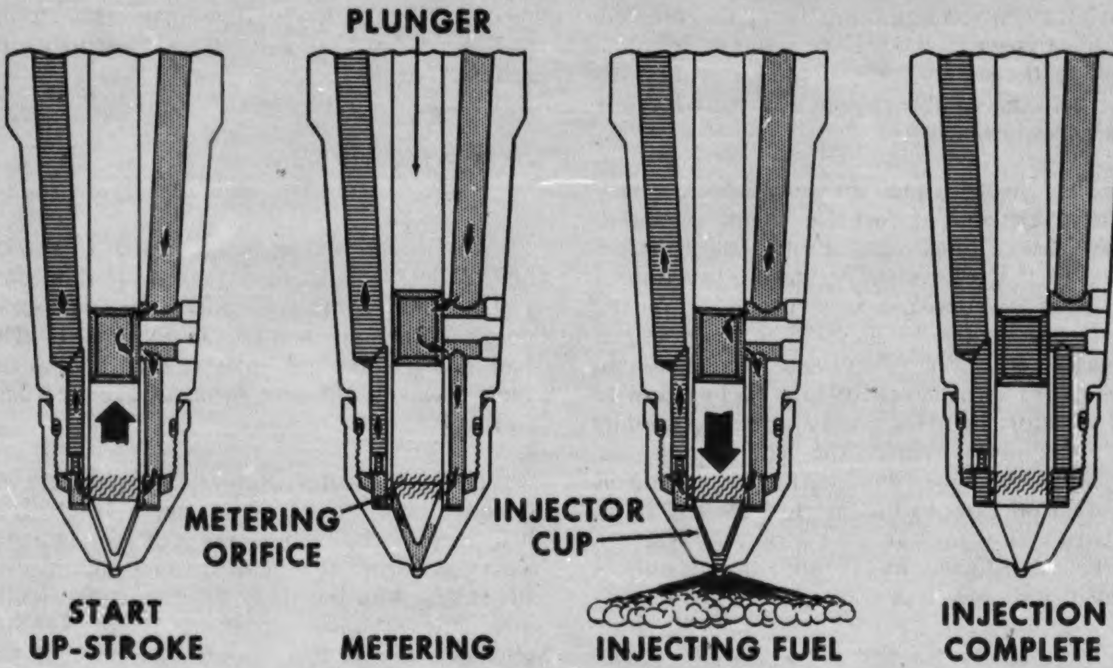
All General Motors diesel engines (GM 645, 567, 278, 268, 71, and 53) use the unit injector system which combines a pump and a fuel spray nozzle in one unit, as shown in figure 10-19. The fuel piping to the unit injector carries oil at the filter discharge pressure (generally about 40-50 psi).

The unit injector is generally installed in the cylinder head, as shown in figure 10-20. It is held in place by an injector crab. The cylinder head has a copper tube into which the injector fits snugly with the spray tip projecting slightly into the cylinder clearance space. Water circulates around the copper tube and cools the lower part of the injector.

Two fuel lines are connected to each injector; one carries fuel to the injector and the other carries away fuel that is bypassed. The


FILTER SCREEN
TACHOMETER SHAFT
PRESSURE REGULATOR
SHUT-DOWN VALVE
GEAR PUMP
PULSATION DAMPER
MAIN SHAFT
IDLE SPRINGS
IDLE SPEED SCREW
MAXIMUM SPEED SPRING
GOVERNOR WEIGHTS
THROTTLE SHAFT

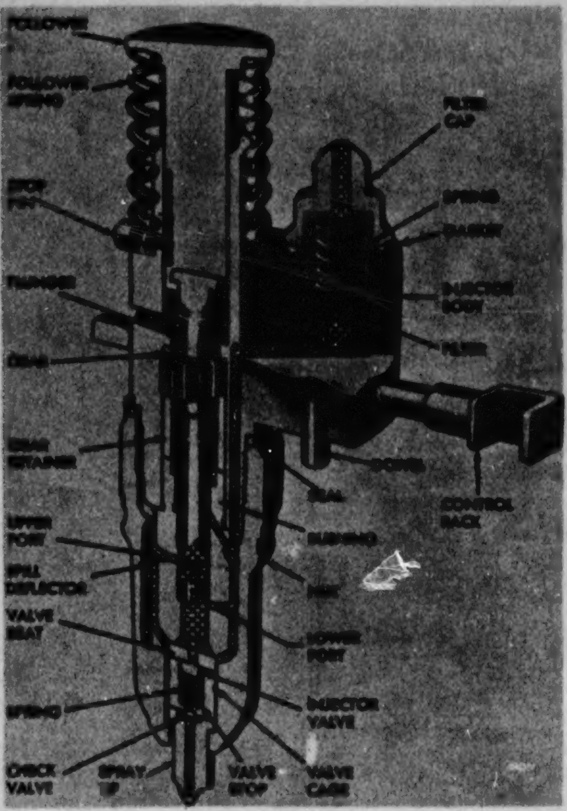
A. PT FUEL PUMP


PLUNGER
METERING ORIFICE
INJECTOR CUP
START UP-STROKE
METERING
INJECTING FUEL
INJECTION COMPLETE

B. INJECTION CYCLE

75.306X

Figure 10-18.—Cummins PT fuel pump and injection cycle.



2.68X

Figure 10-19.—Unit injector assembly.

injector is operated by a rocker arm and push rod which work off the camshaft. The amount of fuel injected is regulated by the control rack which is operated by a lever secured to the control tube.

In the unit injector (sectional view, fig. 10-19), fuel under pressure enters the injector at the inlet side through a filter cap and filter element. (Note: According to NAVSEA, injectors of the type illustrated may be used without a filter.) From the filter element, the fuel passes through a drilled passage into the supply chamber—the area between the plunger bushing and the spill deflector, in addition to the area under the injector plunger within the bushing. The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the annular chamber through two funnel-shaped ports in the plunger bushing.

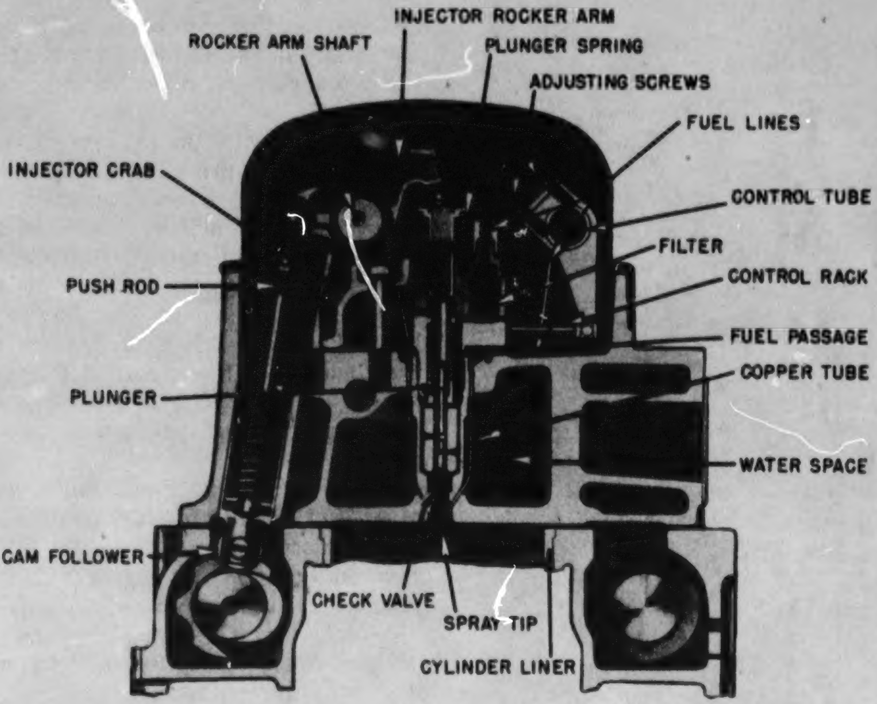
The motion of the injector rocker arm (fig. 10-20) is transmitted to the plunger by the follower, which bears against the follower spring, as shown in figure 10-19. In addition to the reciprocating motion, the plunger can be rotated during operation around its axis by the gear which meshes with the rack. For metering the fuel, an upper helix and a lower helix are machined in the lower part of the plunger. The relation of the helices to the two ports changes with the rotation of the plunger.

There are several types and models of unit injectors. Unit injectors are classified according to the design of the injector valve. Three common types in use are the high valve, the spherical valve, and the needle valve. The high valve injector is described in the following paragraphs, and the principal differences in the other types are indicated.

The basic operation is shown in figure 10-21. As the plunger moves downward under pressure of the injector rocker arm, a portion of the fuel trapped under the plunger is displaced into the supply chamber through the lower port until the port is closed off by the lower end of the plunger. Then, a portion of the fuel trapped below the plunger is forced upward through a central passage of the plunger into the recess and into the supply chamber through the upper port until that port is closed off by the upper helix of the plunger. With the upper and lower ports both closed off, the remaining fuel under the plunger is subjected to increased pressure by the continued downward motion of the plunger.

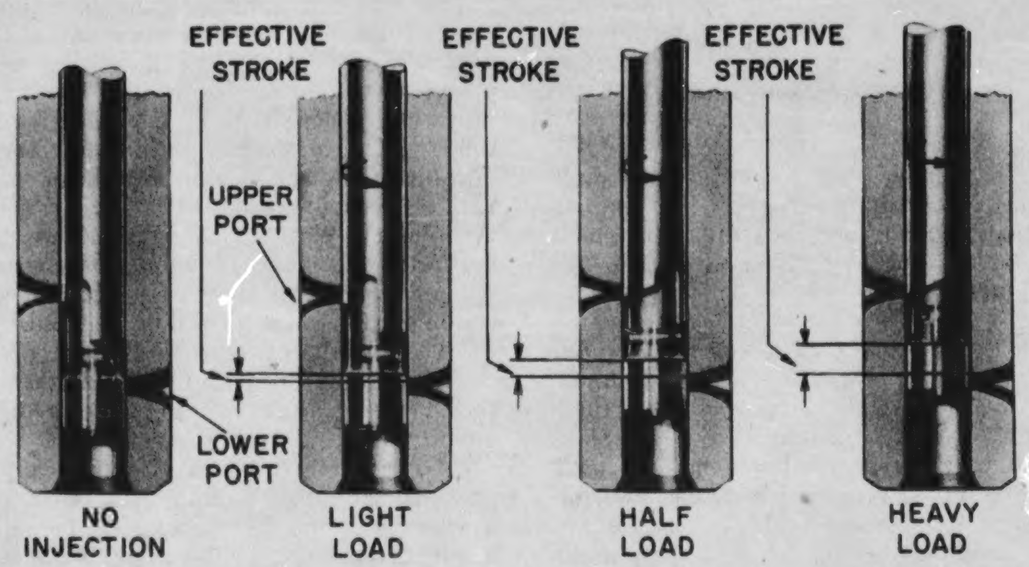
When sufficient pressure is built up, the injector valve is forced off its seat and the fuel is forced through small orifices in the spray tip and atomized into the combustion chamber.

A check valve, mounted in the spray tip, prevents air leakage from the combustion chamber into the fuel injector if the valve is accidentally held open by a small particle of dirt. The injector plunger is then returned to its original position by the injector follower (plunger) spring.


INJECTOR ROCKER ARM
ROCKER ARM SHAFT
PLUNGER SPRING
ADJUSTING SCREWS
FUEL LINES
INJECTOR CRAB
CONTROL TUBE
FILTER
PUSH ROD
CONTROL RACK
FUEL PASSAGE
COPPER TUBE
PLUNGER
WATER SPACE
CAM FOLLOWER
CHECK VALVE
SPRAY TIP
CYLINDER LINER

75.145

Figure 10-20.—Mounting of the unit injector in the cylinder head.


EFFECTIVE STROKE
EFFECTIVE STROKE
EFFECTIVE STROKE
UPPER PORT
LOWER PORT
NO INJECTION
LIGHT LOAD
HALF LOAD
HEAVY LOAD

75.146

Figure 10-21.—Injection and metering principles of a unit injector.

On the return upward movement of the plunger, the high-pressure cylinder within the bushing is again filled with fuel oil through the ports. The constant circulation of fresh, cool fuel through the injector renews the fuel supply in the chamber, helps cool the injector and, also, effectively removes all traces of air which might otherwise accumulate in the system and interfere with accurate metering of the fuel.

The fuel injector outlet opening returns the excess fuel oil to the fuel return manifold and from there back to the fuel tank.

Changing the position of the helices, by rotating the plunger, retards or advances the closing of the ports and the beginning and ending of the injection period. At the same time, it increases or decreases the amount of fuel injected into the cylinder. Look again at the various plunger positions from light load to heavy load shown in figure 10-21. With the control rack pulled out all the way (no injection position), the upper port is not closed by the helix until after the lower port is uncovered. Consequently, with the rack in this position, all of the fuel is forced back into the supply chamber and no injection of fuel takes place. With the control rack pushed in (full injection position), the upper port is closed shortly after the lower port has been covered, thus producing a maximum effective stroke and maximum injection. From the no injection position to the full injection position (full rack movement), the contour of the upper helix advances the closing of the ports and the beginning of injection.

The injector valve assembly is located in the spray tip of spherical valve type fuel injector assemblies, whereas the high valve type injectors incorporate the valve assembly in a valve cage located between the valve seat and the spray tip. Cross sections of these injectors are shown in figure 10-22. (According to NAVSEA, injectors of the types illustrated also may be used without a filter.) In spherical valve injectors, the check valve is in a recess on the top of the valve seat and is held in place by a spacer located between the valve seat and injector bushing. The check valve in high valve type injectors is located below the valve assembly in a recess in the spray tip and is held in place by the valve cage.

Due to the difference in location of the injector valve assembly, spherical valve injectors require a longer plunger and bushing assembly, a longer spill deflector, and a different spray tip and injector nut.

Spherical valve injector assemblies have a lighter plunger spring and a three-piece follower assembly consisting of the follower, a follower guide, and follower pin. High valve injectors use a one-piece follower.

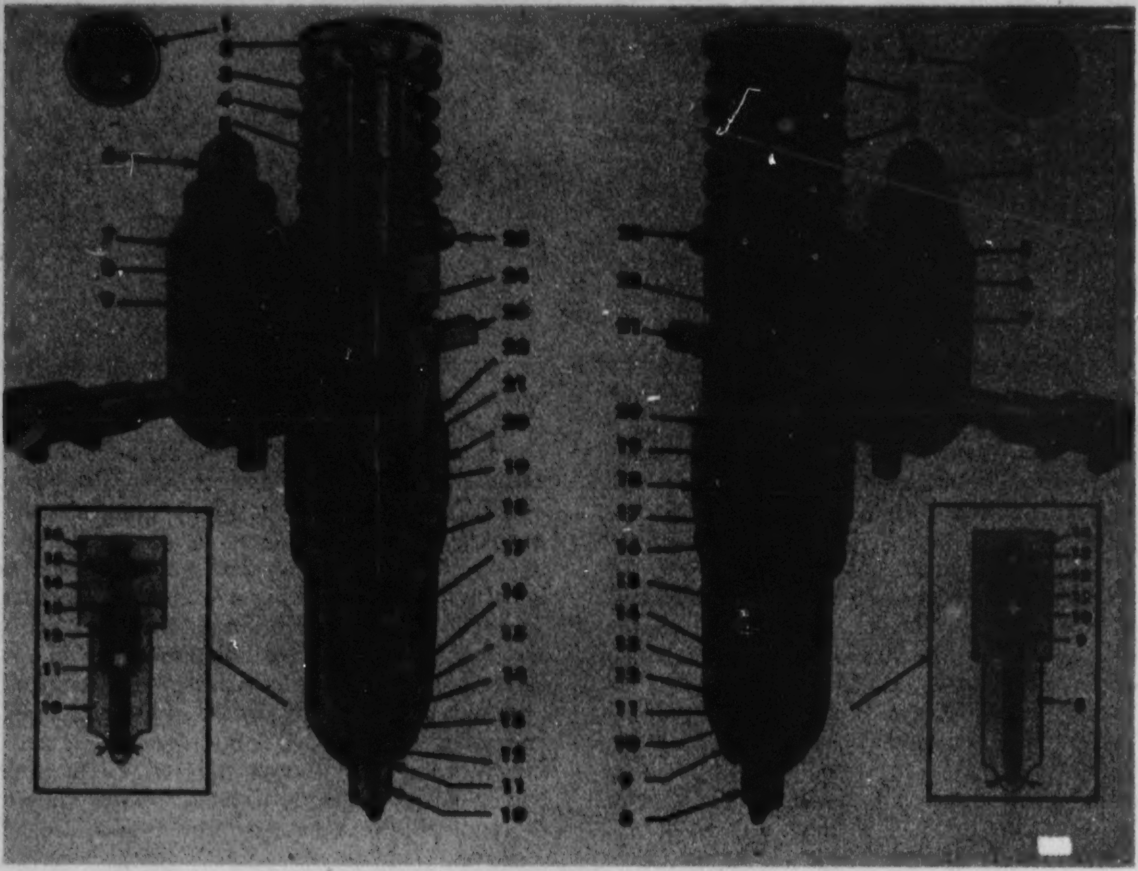
Operation and servicing procedures are essentially the same for both spherical valve type and high valve type injector assemblies.

A later type GM unit injector is the needle valve injector (N-type design) shown in figure 10-23. The needle valve injector has a higher opening pressure (2,800 psi at the needle valve as compared to 600 psi) than was used in earlier injector models. A higher opening pressure provides better atomization of the first part of the fuel charge and better atomization at low fuel input. The needle valve injector differs from earlier designs primarily in the plunger, bushing, and spray tip. Do NOT intermix needle valve injectors with other type injectors in the same engine because injection characteristics are not the same in different types of injectors.

The principles by which injecting and metering are accomplished are almost identical in all GM unit injectors. These principles are illustrated in figure 10-21.

INJECTION NOZZLES

There are two general types of injection nozzles: the open type and the closed type. The open type is usually a simple spray nozzle with a check valve which prevents passage of the high-pressure gases from the engine cylinder to the pump. Although the open type nozzle is simple, it does not give proper atomization; therefore, it is not generally used. The closed type nozzle is more commonly used. There are two main classifications of closed type nozzles: the pintle nozzle and the hole type nozzle.



SPHERICAL VALVE INJECTOR ASSEMBLY

— LEGEND —

1—NUMBER TAG
2—FOLLOWER
3—FOLLOWER GUIDE
4—FOLLOWER SPRING
5—FOLLOWER PIN
6—FILTER CAP
7—FILTER CAP GASKET
8—FILTER SPRING
9—FILTER ELEMENT
10—SPRAY TIP
11—VALVE STOP
12—VALVE SPRING
13—VALVE
14—VALVE SEAT
15—CHECK VALVE
16—SPACER
17—PLUNGER BUSHING
18—SPILL DEFLECTOR
19—PLUNGER
20—NUT
21—GEAR RETAINER
22—SEAL RING
23—RACK
24—GEAR
25—FOLLOWER STOP PIN

HIGH VALVE INJECTOR ASSEMBLY

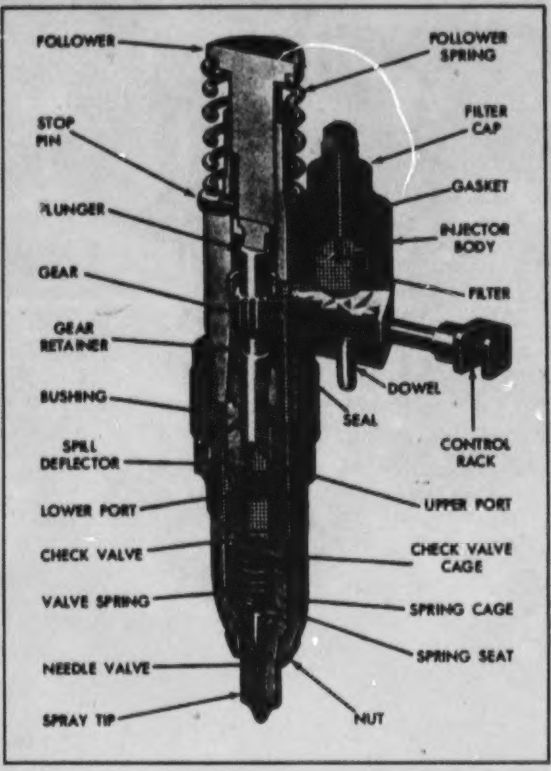
— LEGEND —

1—NUMBER TAG
2—FOLLOWER
3—FOLLOWER SPRING
4—FILTER CAP
5—FILTER CAP GASKET
6—FILTER SPRING
7—FILTER ELEMENT
8—SPRAY TIP
9—CHECK VALVE
10—VALVE STOP
11—VALVE CAGE
12—VALVE SPRING
13—VALVE
14—VALVE SEAT
15—PLUNGER BUSHING
16—SPILL DEFLECTOR
17—PLUNGER
18—NUT
19—GEAR RETAINER
20—SEAL RING
21—RACK
22—GEAR
23—FOLLOWER STOP PIN

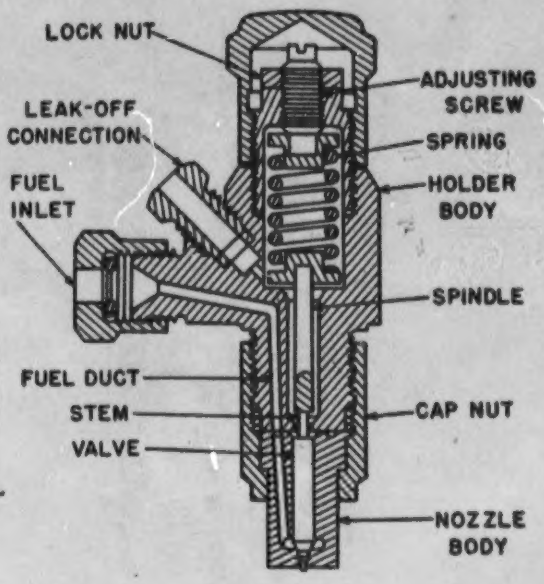
75.147X

Figure 10-22.—Injector assemblies (GM 71 series).

Figure 10-24 is a cutaway sectional view of a Bosch injector, showing details of the nozzle holder and a hole type nozzle. The high-pressure oil from the injection pump enters the nozzle holder body through a metal-edge strainer. From the strainer the oil goes through a drilled fuel passage which extends to the bottom of the nozzle holder body. The nozzle, with its spray tip, is held against the bottom of the nozzle holder by the cap nut. A groove in the top of


FOLLOWER
FOLLOWER SPRING
STOP PIN
FILTER CAP
GASKET
PLUNGER
INJECTOR BODY
GEAR
FILTER
GEAR RETAINER
BUSHING
DOWEL
SEAL
CONTROL RACK
SPILL DEFLECTOR
LOWER PORT
UPPER PORT
CHECK VALVE
CHECK VALVE CAGE
VALVE SPRING
SPRING CAGE
SPRING SEAT
NEEDLE VALVE
SPRAY TIP
NUT

75.144
Figure 10-23.—Needle valve injector assembly.


LOCK NUT
ADJUSTING SCREW
LEAK-OFF CONNECTION
SPRING
FUEL INLET
HOLDER BODY
SPINDLE
FUEL DUCT
STEM
CAP NUT
VALVE
NOZZLE BODY

256.59X
Figure 10-24.—Sectional view of Bosch injection nozzle assembly.

the nozzle forms a circular passage for the fuel oil between the nozzle and holder.

Several vertical ducts carry the oil from the circular passage to the oil cavity, near the bottom of the nozzle. The nozzle valve cuts in sharply to a narrower diameter in the oil cavity, providing a surface against which the high-pressure oil in the oil cavity can act to raise the valve from its seat in the spray tip. When the valve is raised from its seat, the oil sprays out to the combustion chamber through a ring of small holes.

The valve has a narrow stem which projects into the central bore of the nozzle holder where it bears against the bottom of the spindle. The spindle is held down by the pressure adjusting spring. Whenever the upward force of the high-pressure oil acting on the needle valve exceeds the downward force of the spring, the valve can rise. The moment the spring force is greater, the valve will snap back to its seat. The spring tension is regulated by a pressure adjusting screw which is held by a locknut.

Regardless of the close lapped fit of the valve, some oil leaks past the valve and rises through the central bore of the nozzle holder. This oil lubricates the moving parts of the injector and then drains off through the oil drain connection of a drip tank. There is a bleeder screw which can be used to bypass fuel oil to the nozzle, sending the fuel directly to the oil drain. Bleeder screws can be used to determine which injector is at fault when a cylinder is misfiring.

The pintle nozzle and the hole nozzle are illustrated in figure 10-25.

The valve of the pintle nozzle has an extension which protrudes through the hole in the bottom of the nozzle body and produces a hollow cone-shaped spray. The included angle of the spray cone may be between zero and 60°, dependent on the type of combustion chamber in which it is used. A pintle nozzle generally

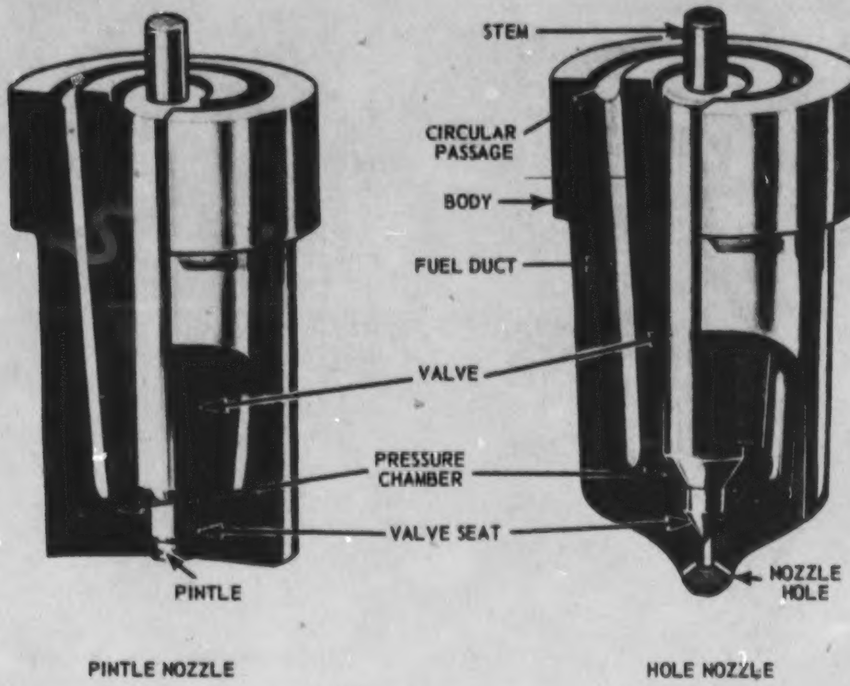


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Figure 10-25.—Pintle nozzle and hole type nozzle.

opens at a lower pressure than the hole nozzle because fuel flows more readily from the large hole of the pintle type. Although atomization of the fuel is not so complete in the pintle type, penetration into the combustion space is greater. Consequently, pintle nozzles are used in conjunction with the auxiliary chamber system, wherein mixing of fuel and air is largely dependent on combustion reaction or turbulence.

The multiple hole type nozzle provides good atomization but less penetration. It is used with the open type combustion chamber in which high atomization is more important than penetration. The spray pattern of the hole type nozzle is dependent on the number and placement of the holes or orifices.

Regardless of design, all nozzles and tips function to direct the fuel into the cylinder in a pattern that will bring about the most efficient combustion. Obviously, the slightest defect in nozzles and tips will affect engine operation. The troubles and their causes, which may be encountered in either the spray tip of a unit injector or in a separate spray nozzle, are relatively the same.

FUEL INJECTION EQUIPMENT CASUALTIES AND REPAIRS

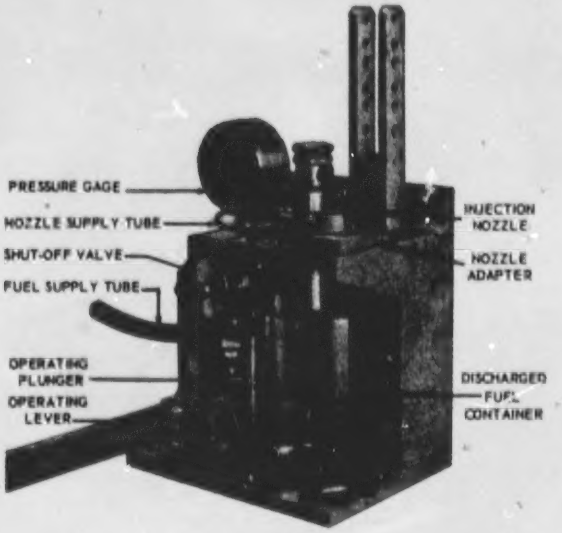
Some of the most common casualties to fuel injection equipment are incorrect pressure, distorted spray patterns and leaky nozzles and injector spray tips.

INCORRECT PRESSURE

An incorrect nozzle opening pressure or incorrect injector pop pressure will influence engine efficiency and performance. The exact effect will vary according to the type of combustion space served. When opening pressure is greater than the specified value, it tends to decrease the amount of fuel injected and also tends to retard the start of injection. A low nozzle opening pressure decreases the atomization of the fuel at low speeds and, in extreme cases, will cause dribble. It also tends to increase the amount of fuel injected which will cause a smoky exhaust from the affected engine cylinder. The best protection against trouble from this source is a periodic check of the nozzle or injector with an appropriate tester. Test stands will vary, depending on the manufacturer, but all operate on the same principle. The type of test stand illustrated in figure 10-26 is intended primarily for activities that do a considerable amount of nozzle and injector reconditioning work.

Tests that may be performed on this type of fixture are: spray tip orifice test, valve opening pressure test, and holding pressure test. You will find details on test procedures in the appropriate fuel injection equipment maintenance manual.

CAUTION: When you are using a tester, you must be aware that the penetrating power of the fuel oil spray is sufficient to drive oil through your skin. Since the fuel oil can cause blood poisoning, you MUST keep all parts of your body out of the line of the fuel spray.



121.14X

Figure 10-26.–Universal test stand.

When the opening pressure of a nozzle is too high, the cause will depend on the fuel system involved. For example, if a Bosch nozzle opening pressure is too high, or if the nozzle fails to open, the pressure spring may be improperly adjusted, the nozzle valve may be stuck in the nozzle body, or the nozzle orifices may be clogged. In a GM unit injector, if the pressure is too high because of a maladjusted pressure spring, the valve must be disassembled and a new spring must be installed. Since the cause of excessive opening pressure depends on the fuel system involved, you must be familiar with the equipment with which you are working and follow the applicable injection system technical manual.

Unit injectors should be tested if improper opening pressure is suspected. Injectors equipped with needle valve assemblies cannot be tested for opening pressure without special equipment because such tests will result in severe damage to the test equipment and the injector. You will find complete instructions for testing this type of injector in the fuel injector maintenance manual.

When a pressure can be built up considerably higher than the pop pressure prescribed for a unit injector, it is usually due to improper assembly of the injector. In certain models of some unit injectors, it is possible to reverse one of the check valves. When this is done, the check valve will seat when the fuel tends to flow from the injector to the engine.

A pop pressure that is too low for a unit injector may be due to a weak valve spring or dirty sealing surfaces. In nozzles where adjustments are possible, a low opening pressure may be due to a broken or an improperly adjusted pressure spring.

DISTORTED SPRAY PATTERN

Distortion of the spray pattern of a nozzle or injector may be indicated by low firing

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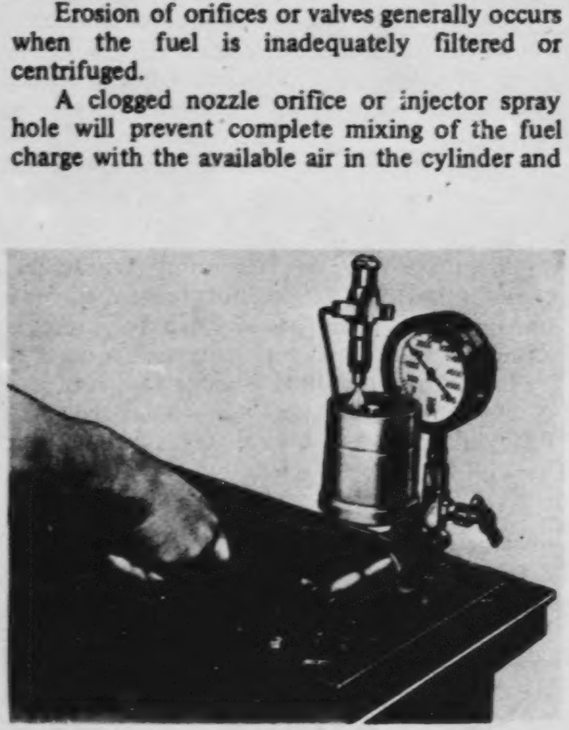
pressure, loss of power, smoky exhaust, or local deposits of carbon within the combustion space. Nozzles and injector spray tips are designed so that combustion should start before any appreciable quantity of fuel has struck the relatively cold surfaces of the combustion space. Orifices are drilled to take advantage of air currents in creating turbulence. For efficient combustion, the spray pattern must not become distorted.

Spray patterns can be checked with a tester similar to either of those shown in figures 10-26 and 10-27. However, throttling type pintle nozzles are difficult to test with a hand tester because of the high number of strokes per minute required to produce a representative spray pattern. A motor-driven test stand is highly desirable for testing a nozzle of this type.

Distortion of a spray pattern may be caused by eroded valves, eroded or clogged orifices, or a broken pintle, dependent on the type of nozzle or spray tip.

Erosion of orifices or valves generally occurs when the fuel is inadequately filtered or centrifuged.

A clogged nozzle orifice or injector spray hole will prevent complete mixing of the fuel charge with the available air in the cylinder and will result in a drop in the power output of that cylinder, causing other cylinders to be overloaded. Inspect nozzles and injectors carefully when removed from the engine to determine whether any of the orifices are clogged.



121.15X

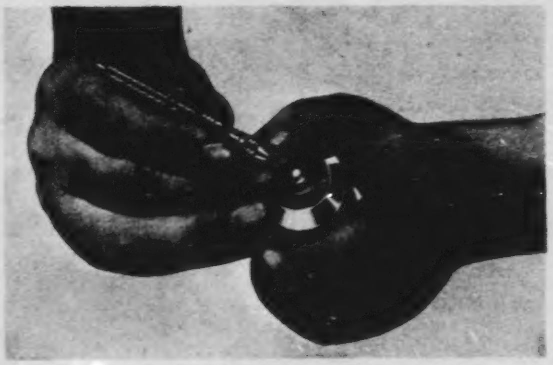
Figure 10-27.—Testing a spray nozzle.

When you handle pintle type nozzles, be extra careful so that you do not damage that portion of the nozzle valve which protrudes below the bottom of the nozzle body. When removing carbon from the nozzle body, do not inadvertently remove the pintle. Also, it is possible to break off the pintles by striking or dropping the nozzle and holder on a hard surface.

Distortion of the spray pattern is usually caused by dirt in the nozzle. You should clean nozzle orifices as illustrated in figure 10-28. Hold the cleaning wire at the same angle as the drilled orifice. Otherwise the orifice may be damaged or the cleaning wire may break as it passes through the opening. If the spray is still distorted after the nozzle has been thoroughly cleaned, the cause is probably eroded parts. Erosion will require replacement of the nozzle.

LEAKY NOZZLES AND INJECTOR SPRAY TIPS

Dribbling from a nozzle or an injector may result in smoky operation, detonation, loss of



2.45X

Figure 10-28.—Cleaning nozzle orifices.

power, crankcase dilution, or excessive carbon formation on cylinder injection equipment and other surfaces of the combustion chamber. When a nozzle or injector spray tip is suspected of leakage, it should be checked on the appropriate tester.

Dribbling of nozzles may be due to a damaged valve or valve body seat, a dirty nozzle, a broken pressure adjusting spring or screw, or a nozzle valve stuck in the nozzle body. Leakage from a spray tip or an injector may be due to damaged sealing surfaces or broken valve springs.

Many leaking or dribbling nozzles may be repaired and placed back in service. When a nozzle is found to be leaking, soak it overnight in a suitable solvent, and then remove the accumulated deposits with brass tools or tools of softer metal. Secure the nozzle body in an appropriate holding device, and coat the nozzle valve with clean mutton tallow and rotate it into the valve body. Usually, this will remove the surface deposits that cause the leakage. If the leakage does not stop, lapping, explained in detail in the fuel injection equipment maintenance manual, may be necessary. Lapping is a precision operation and, unless all the precautions listed in the manual are followed, the nozzle may be ruined.

You must replace any nozzle that is cracked, extensively eroded, or so badly stuck that valve removal is not possible. Defective nozzles should be shipped to a reconditioning center.

When assembling a nozzle or injector, be careful to insert the parts in their proper positions. After assembly, you must test the unit to determine whether it performs as specified in the applicable maintenance manual. The unit must not be used if it does not meet the specifications.

PURGING THE DIESEL ENGINE FUEL INJECTION SYSTEM

When an engine fails to operate, stalls, misfires, or knocks, there may be air in the high-pressure pumps and fuel lines. If air is present in the system, compression and expansion of such air may take place without the injection valve's opening.

You can determine the presence of air in a fuel system by bleeding a small amount of fuel from the top of the fuel filter or by slightly loosening the bleeder screw or plug. If the fuel appears quite cloudy, it is likely that there are small bubbles of air in the fuel.

In working with fuel systems, you should remember that if air is entering a fuel line, the pressure within the fuel line must be lower than atmospheric pressure. The smallest of holes in the transfer pump suction piping will allow enough air to flow into the system to air bind the high-pressure pumps. Carefully inspect all fittings in the suction piping. A loose fitting or a damaged thread condition will allow air to enter the system. On installations where flanged connections are used, be sure to check the condition of the gaskets. Inspect tubing, especially copper, carefully for cracks which may result from constant vibration.

If an engine is allowed to run out of fuel, you can expect trouble from air which enters the fuel system. If there is a considerable amount of air in the filter, a quick method of purging the system of air is to remove the filling plugs on top of the filter and pour in clean fuel oil until all air is displaced. You can then remove any air remaining in the system by using the hand priming pump.

For example, in the fuel system illustrated in figure 10-29, open the line between the pump and strainers. Operate the pump until all air is removed and only clear fuel flows from the line. Then close the line. Repeat the same procedure at other points in the system such as between the strainers and the filters, between the filters and the high-pressure pumps, and at the overflow line connection on the high-pressure pump housing. In small, high-speed diesel engines, you may need to prime only at the overflow connection. Since priming high-pressure lines is time consuming, attempt to start the engine before purging these lines.

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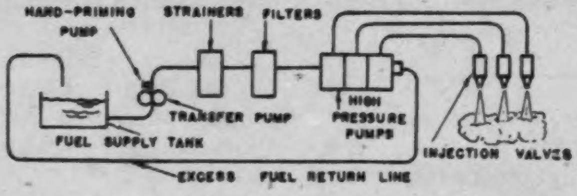

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Figure 10-29.—Schematic drawing of a fuel system.

However, the engine must not be cranked for more than the specified interval of time. If the engine still fails to start, it will be necessary to prime the high-pressure lines. Since the procedure necessary to prime high-pressure lines varies considerably with different installations, follow the manufacturer's instructions for the proper procedure.

ENVIRONMENTAL POLLUTION CONTROL

Environmental pollution is the condition that results when there are chemical, physical, or biological agents in the air, water, or soil which so alter the natural environment that an adverse effect is created on human health or comfort, fish and wildlife, other aquatic resources and plant life, structures and equipment to the extent of producing economic loss, impairing recreational opportunity, or marring natural beauty. To reduce air pollution at sea, the Navy has authorized its ships to burn distillate fuel rather than Navy Special Fuel Oil (NSFO). The distillate fuel, unlike NSFO, has a low ash and sulfur content and contains no residual component; therefore, it burns clean. Oil pollution, as air pollution, has a serious effect on our environment. Oil spill cleanup operations are both difficult and costly. There are strict regulations and water quality standards which apply to the navigable waters.

Each year many thousands of dollars are spent because of oil spills. Oil spillage is not only costly in money value, but its quality affects our natural environment, damages the hulls of yachts or boats, pollutes our beaches, and destroys much fish and wildlife. Much of this can be avoided and many organizations including the United States Navy, are doing as much as possible to prevent such pollution. All Enginemen must be familiar with current oil and water pollution control regulations.

The Oil Pollution Act of 1961 prohibits the discharge of oil or water containing oil into the sea within 50 miles of any land and establishes certain prohibited zones which in some areas extend as far as 150 miles from land. In accordance with the provisions of the Act of 1961, the discharge of oil or any oil mixture is not deemed unlawful when such action is required, for the safety of the ship or its cargo, and for the saving of life at sea. In addition, the escape of oil or any oily mixture is not considered unlawful if it results from damage to the ship or from unavoidable leakage, provided that all reasonable precautions have been taken, after occurrence of the damage or discovery of the leakage, to prevent or minimize the escape.

The Federal Water Pollution Control Act prohibits the discharge of oil by any person from any waterborne vessel of any type or from any onshore or offshore facility into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the Contiguous Zone. (The Contiguous Zone is 12 miles from the baseline from which the territorial sea is measured.) Restrictions within the Contiguous Zone are considerably more strict than those outside the zone. Copies of applicable regulations should be maintained in the log room. There are engineering practices that, if followed, should prevent or minimize oil spillage in waters where the resultant contamination is likely to cause damage.

When the ship is located in the waters within limits defined in the Oil Pollution Act and the Federal Water Pollution Control Act:

1. Do not normally transfer fuel oil while the ship is underway. This practice not only reduces oil spillage (with its consequent wide dispersal due to the movement of the ship), but also reduces the possibility of an engineering casualty in restricted waters.
2. Limit the transfer of fuel oil to daylight hours, and establish and maintain sound-powered telephone communications between competent personnel stationed at all tanks and pumps involved in the fuel transfer and at lookout stations so located that personnel can observe fuel tank air vents and overflows at all times.
3. Do not discharge ballast overboard from piping or tanks except into a sludge barge or an oil-water separator.
4. Establish in each watch section an organized oil pollution party instructed in and capable of localizing, containing, and disposing of oil spillage and slicks.
5. Indoctrinate and instruct all personnel who man watchstations on weatherdecks (whether moored, at anchor, or underway) in observing, recognizing, and reporting all oil spillage and oil slicks.

Pump all bilges prior to entering waters within the limits defined by regulations. Within restricted waters, bilges may be pumped to contaminated tanks or to other tanks (ballast or fuel) temporarily designated by the engineer officer to receive bilge water pending its disposal in safe unrestricted areas at sea. In many ports sludge barges are available for the disposal of bilge water.

CHAPTER 11

PROPULSION CONTROL SYSTEMS

The basic principles of propulsion control systems are the subject of this chapter. We will first discuss the methods and devices for controlling engines and, then, the devices and systems (including shaft speed and direction and engine load) which control the entire propulsion plant.

ENGINE CONTROLS

To control an engine means to keep it running at a desired speed, either in accordance with or regardless of the changes in the load carried by the engine. The degree of control required depends on two factors: the engine's performance characteristics and the type of load which it drives.

In diesel engines, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder during each intake event. The amount of fuel injected into the cylinders controls combustion and thus determines speed and power output of a diesel engine. A governor regulates the flow of fuel.

GOVERNORS

A governor is a speed-sensitive device which maintains a reasonably constant engine speed regardless of load variation. All governors used on diesel engines control engine speed by regulating the quantity of fuel delivered to the cylinders; these governors may be classified as SPEED-REGULATING GOVERNORS. Governors may also be classified according to the function or functions they perform, the forces they use in operation, and the means by which they operate the fuel control mechanism.

The function of a governor on a given engine is determined by the load on the engine and the degree of control required. Governors are classified according to their function as: constant-speed, variable-speed, speed limiting, and load limiting.

Some installations require a constant engine speed from a no-load condition to a full-load condition. Governors used to maintain one speed, regardless of load, are called CONSTANT-SPEED governors. Governors, which maintain any desired engine speed over a wide speed range and which can be set to maintain a desired speed in that range, are classified as VARIABLE-SPEED governors.

Speed control devices which are used to keep an engine from exceeding a specified maximum speed and from dropping below a specified minimum speed are classified as SPEED-LIMITING governors. (Some speed-limiting governors limit maximum speed only. Some engine installations need a control device to limit the load which the engine will handle at various speeds. Such devices are called LOAD-LIMITING governors. Some governors are designed to perform two or more of these functions.

Terminology

Before considering the operating principles of governors, you should become familiar with these terms.

1. SPEED DROOP is the decrease in speed of the engine from a no-load condition to a

full-load condition. Speed droop is expressed in rpm, or more commonly as a percentage of normal or average speed.

2. ISOCHRONOUS GOVERNING is maintaining the speed of the engine truly constant, regardless of the load. This means governing with perfect speed regulation or zero speed droop.

3. HUNTING is the continuous fluctuation (slowing down and speeding up) of the engine speed from the desired speed. Hunting is caused by overcontrol by the governor.

4. STABILITY is the ability of the governor to maintain the desired engine speed without fluctuations or hunting.

5. SENSITIVITY is the change in speed required before the governor will make a corrective movement of the fuel control mechanism and is generally expressed as a percentage of the normal or average speed.

6. PROMPTNESS is the speed of action of the governor. It identifies the time interval required for the governor to move the fuel control mechanism from a no-load position to a full-load position. Promptness depends on the power of the governor; the greater the power, the shorter the time required to overcome the resistance.

Operating Principles

Most of the governors installed on diesel engines used by the Navy operate by the centrifugal force of rotating weights (flyballs) and the tension of a helical coil spring(s). On this basis, these governors are generally referred to as spring-loaded centrifugal governors.

In spring-loaded centrifugal governors, two forces oppose each other. One of these forces is produced by a spring(s) and may be varied either by an adjusting device or by the manual throttle. The other force is produced by the engine. Weights attached to the governor drive shaft are rotated by the engine, and a centrifugal force is created. The amount of the centrifugal force varies directly with the speed of the engine.

Transmitted to the injectors through a connecting linkage, the force of the spring(s) tends to increase the amount of fuel delivered to the cylinders. On the other hand, the centrifugal force of the rotating weights, through connecting linkage, tends to reduce the amount of fuel injected. When the two opposing forces are equal, or balanced, the speed of the engine remains constant.

To illustrate how the centrifugal governor works: Assume that an engine is operating under load and that the opposing forces in the governor are balanced, so that the engine speed is constant. If the load is increased, the engine speed will decrease, thereby reducing the centrifugal force of the flyballs. The spring pressure then becomes the greater force and causes the fuel control mechanism to increase the amount of fuel delivered to the engine. The increase in fuel causes an increase in engine speed until the forces are again in balance.

When the load on an engine is reduced or removed, the engine speed increases and the centrifugal force within the governor increases. The centrifugal force then becomes greater than the spring pressure and causes the fuel control linkage to reduce the amount of fuel delivered to the cylinders; this causes the engine speed to decrease until a balance between the opposing forces is again reached and engine speed becomes constant.

Regulation of Fuel Control Mechanisms

Governors may be classified according to the method by which fuel control mechanisms are regulated. In some governors, the centrifugal force of the rotating weights regulates the fuel supply directly through a mechanical linkage which operates the fuel control mechanism. In other governors, the centrifugal force of the rotating weights regulates the fuel supply indirectly by moving a hydraulic pilot valve which controls oil pressure. Oil pressure is then exerted on either side of a power piston which operates the fuel control mechanism.

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Governors that regulate the fuel supply directly (through mechanical linkage) are called MECHANICAL governors, and those that control the fuel indirectly (through oil pressure) are called HYDRAULIC governors. Simple governors of the mechanical and hydraulic types are shown in figures 11-1 and 11-2, respectively.

Note that in the illustration of the mechanical governor, the weights (or flyballs) are in an upright position. This indicates that the centrifugal force of the weights and the pressure of the spring are balanced; in other words, the engine is operating at constant load and speed.

In the illustration of the hydraulic governor, the positions of the parts indicate that the engine is responding to an increase in load with a resultant decrease in engine speed. Note that the weights tilt inward at the top. As engine speed decreases, the spring pressure overcomes the centrifugal force of these rotating weights. When the spring pressure is greater than the centrifugal force of the flyballs, the governor mechanism permits oil under pressure to force the piston to increase the fuel valve opening. The increased fuel supply causes an increase in engine power output and speed. The governor regulates the fuel supply to develop sufficient power to handle the increase in load.

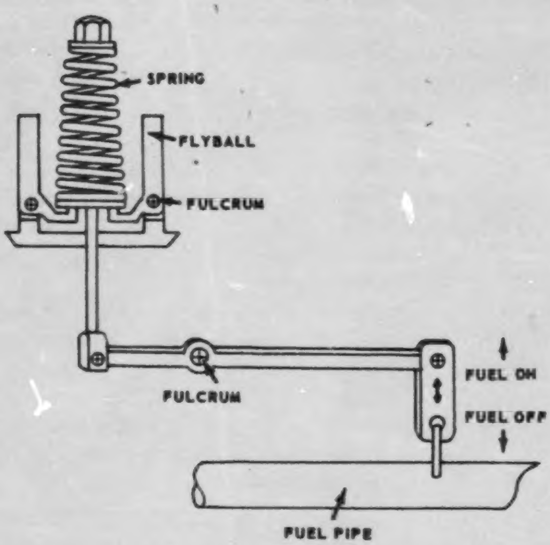

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Figure 11-1.—Simple mechanical governor.

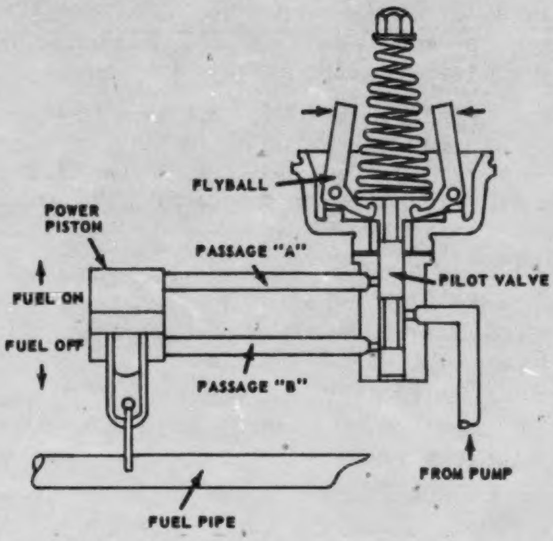

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Figure 11-2.—Simple hydraulic governor.

There is always a lag between a change in fuel setting and the time the engine reaches the new desired speed. Even when the fuel controls are set as required during a speed change, hunting caused by overshooting will occur. As long as engine speed is above or below the desired new speed, the simple hydraulic governor will continuously adjust (overcorrect) the fuel setting to decrease or increase the delivery of fuel. For this reason, a hydraulic governor must have a mechanism that will discontinue changing the fuel control setting slightly before the new setting has actually been reached. This mechanism, used in all modern hydraulic governors, is called a compensating device.

One type of compensating device is illustrated in figure 11-3. The pilot valve plunger operates in a movable pilot valve bushing in which are located the parts that control the oil flow. The receiving compensating plunger controls the movement of the valve bushing

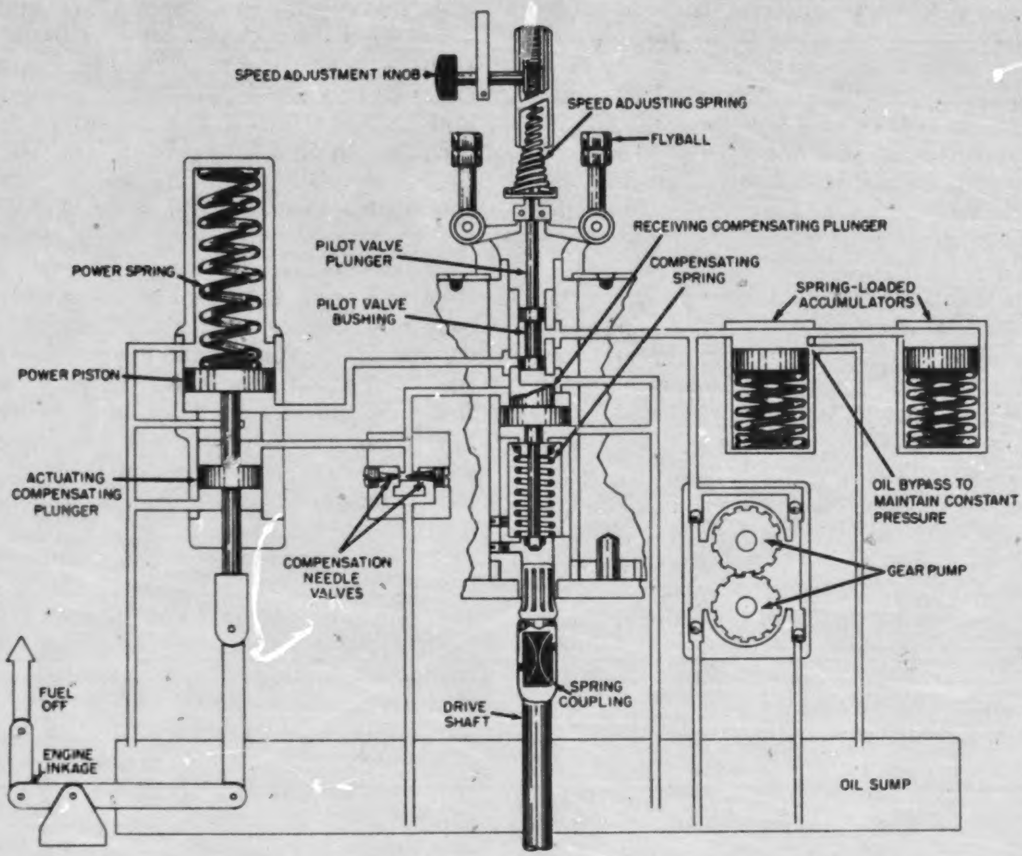
SPEED ADJUSTMENT KNOB
SPEED ADJUSTING SPRING
FLYBALL
RECEIVING COMPENSATING PLUNGER
PILOT VALVE PLUNGER
COMPENSATING SPRING
POWER SPRING
SPRING-LOADED ACCUMULATORS
PILOT VALVE BUSHING
POWER PISTON
ACTUATING COMPENSATING PLUNGER
OIL BYPASS TO MAINTAIN CONSTANT PRESSURE
COMPENSATION NEEDLE VALVES
GEAR PUMP
FUEL OFF
SPRING COUPLING
DRIVE SHAFT
ENGINE LINKAGE
OIL SUMP

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Figure 11-3.—A hydraulic governor with compensating device.

during a speed change. The compensating action of the valve bushing is controlled hydraulically by transfer and leakage of oil between the compensating receiving plunger and the compensating actuating piston. The rate of compensation is adjusted by regulating the oil leakage through the compensating needle valve. If the compensating needle valves are adjusted correctly, only a slight amount of hunting will occur after a load change. This hunting will quickly be dampened out, resulting in stable operation through the operating range of the governor.

Hydraulic governors are more sensitive than mechanical governors. The mechanical governor is more commonly used on small engines which do not require extremely close regulation of fuel. Hydraulic governors are more suitable for larger engines which require more accurate regulation of fuel.

OVERSPEED SAFETY DEVICES

Engines that are maintained in proper operating condition seldom reach speeds above those for which they are designed. However, conditions may occur to cause excessively high speeds. Operation of a diesel engine at excessive speeds is extremely dangerous because of the relatively heavy construction of the engine's rotating parts. A high speeding engine develops inertial and centrifugal forces which may seriously damage parts or even cause them to fly apart. Therefore, you MUST know why an engine may reach a dangerously high speed and how to bring it under control when excessive speed occurs.

In some two-stroke cycle engines, lubricating oil may leak into the cylinders as a result of leaky blower seals or broken piping. Even though the fuel is shut off, the engine may continue to operate, or even "run away," as a result of the combustible material coming from the uncontrolled source. Engines in which lubricating oil may accumulate in the cylinders generally have an automatic mechanism which shuts off the intake air at the inlet passage to the blower. If there is no air shutoff mechanism and if shutting off the fuel will not stop an engine which is overspeeding, a cloth article such as a blanket or a pair of dungarees should be placed over the engine's intake to stop airflow which will stop the engine.

Excessive engine speeds are more commonly found where there is an improperly functioning regulating governor than where lubricating oil accumulates in the cylinders. To stop an engine which is overspeeding because of lubricating oil in the cylinders, stop the flow of intake air. To accomplish an emergency shutdown or reduction of engine speed when the regulating governor fails to function properly, shut off or decrease the fuel supply to the cylinders.

The fuel supply to the cylinders of an engine may be shut off in several ways, either manually or automatically: (1) Force the fuel control mechanism to the "no fuel" position; (2) block the fuel line by closing a valve; (3) open a valve in the fuel injection line to relieve pressure; or (4) prevent the mechanical movement of the injection pump.

Overspeed safety devices automatically operate the fuel and air control mechanisms. As emergency controls, these safety devices operate only in case the regular speed governor fails to maintain engine speed within the maximum design limit. Devices that bring an overspeeding engine to a full stop by completely shutting off the fuel or air supply are generally called OVERSPEED TRIPS. Devices that reduce the excessive speed of an engine, but allow the engine to operate at safe speeds, are more commonly called OVERSPEED GOVERNORS.

All overspeed governors and trips operate on a spring-loaded centrifugal governor element. In overspeed devices, the spring tension is great enough to overbalance the centrifugal force of the weights until the engine speed rises above the desired maximum. When an excessive speed is reached, the centrifugal force overcomes the spring tension and operates the mechanism which stops or limits the fuel or air supply.

When a governor serves as a safety device, the fuel or air control mechanism is operated by the centrifugal force either directly, as in a mechanical governor, or indirectly, as in a hydraulic governor. In an overspeed trip, the shutoff control is operated by a power spring. The spring is placed under tension when the trip is manually set and is held in place by a latch. If the maximum speed limit is exceeded, a spring-loaded centrifugal weight will move out and trip the latch, allowing the power spring to operate the shutoff mechanism.

Overspeed safety devices must always be operative and must never be disconnected for any reason while the engine is operating. They are to be tested under the Planned Maintenance System either weekly or quarterly, depending on the application of the engine.

PROPULSION CONTROL SYSTEMS

In modern propulsion systems, an integrated system of pneumatic, hydraulic, and electric circuits provides control. Each control system function may use only one of these three mediums, a combination of two, or a combination of all three. The choice of control medium in each instance is based on performing a given control function in the most reliable and efficient manner. In general, the different control mediums are used in the following functions: The basic control medium is pneumatic, and the majority of propulsion control functions are performed by pneumatic circuits. Hydraulic circuits are used wherever a large amount of control actuation power is required, such as applying pitch to controllable pitch propellers. Electric circuits are used extensively for sensing and indicating control system conditions and for alarm systems.

The basic requirements for a propulsion control system are three-fold. First, it must control the main engines' load, keeping the engines equally loaded. Next, it must maintain propeller shaft speed and direction. Finally, it must maintain the desired pitch since some modern diesel-driven ships have controllable pitch propellers.

The engine speed and load are controlled by the governor of each main engine, through a pneumatic signal sent to the governor which increases or decreases the speeder spring tension.

Control of the propeller shaft speed is done by controlling the main engine speed as stated above. Propeller shaft direction of rotation, ahead or astern, on noncontrollable pitch propeller ships is controlled by clutches and reduction gears (Chapter 14).

In ships with controllable pitch propellers, the pitch is controlled by a signal, either pneumatic or hydraulic, sent to an oil direction box. There, the signal is converted to a high-pressure hydraulic force which actuates the propeller blades through a piston and cylinder assembly in the propeller hub.

In most ships with propulsion control systems, the machinery can be operated from three different locations. Local control is usually from a panel mounted on or near the piece of machinery to be operated. The local control station is used for operating a single unit, such as one main engine or cycling the pitch on one propeller.

The enclosed operating station (EOS) has a console for operating one complete propeller shaft, including main engines, propeller pitch, clutches, and all other machinery required for propulsion. On large ships, there may be one EOS for each propeller shaft, while on smaller ships, one EOS will handle all propulsion machinery for the ship.

The third operating station is the pilothouse console which controls propeller shaft speed and pitch or direction. Generally, this station cannot control starting or stopping main engines, operating clutches, or controlling other individual pieces of propulsion machinery.

Both the EOS console and pilothouse console will have instruments to indicate shaft rpm, propeller pitch, and other indicators required for monitoring the propulsion plant.

Propulsion control systems will operate for many years trouble-free with a minimum of care.

Pneumatic systems need a constant source of clean dry air to operate correctly. If the supply of air is dirty or contains oil or water, the various control valves throughout the system will stick and cause malfunctions. All connections should be checked periodically, because if leaks should start, a drop in line pressure will create a faulty signal.

Hydraulic systems' worst enemy is dirt. If any dirt is allowed to enter the system, whether when oil is being added or when other work is being performed, it will create problems. The extremely close clearance of parts in hydraulic components will be damaged. Also, dirt will cause valves in the system to malfunction.

Electrical systems are all but trouble-free with little routine maintenance required. Occasionally problems occur because of loose connections or failure of a component.

Most propulsion control systems will use a combination of all three mediums. In troubleshooting a malfunction, it is usually best to check only one medium at a time until the trouble can be isolated and repaired.

CHAPTER 12

DIESEL ENGINE OPERATING PROCEDURES

In this chapter we shall apply the material in the preceding chapters to the practical problems of operating diesel engines. Since the diesel engines used by the Navy differ widely in design, size, and application, the procedures we will discuss apply only to general type installations. Descriptions will apply generally to the various auxiliary and propulsion diesel installations in Navy ships. Detailed and specific information and operating instructions are provided in the manufacturers' manuals for specific installations and in ship's doctrine such as the Engineering Operation Sequencing Standards (EOSS).

OPERATING INSTRUCTIONS FOR DIESEL ENGINES

There may be occasions when a diesel engine must be started, operated, and secured under a variety of demanding conditions, such as emergencies and casualties in engine supporting systems. Operation under such unusual conditions requires that you know and understand the engine installation, the function of supporting systems, and the reasons for the procedures used in normal operation.

The Engineering Operation Sequencing Standards help to eliminate operational problems for normal situations under which engines are operated. EOSS involves the participation of all personnel from the department head to the watchstander. EOSS is a set of systematic and detailed written procedures which uses charts, instructions, and diagrams for operation and casualty control of a ship's engineering plant and configuration.

Diesel engines are started by hydraulic, electric, or air-powered starting motors. The general starting procedure for all types of systems consists of (1) pre-operational checks, (2) aligning supporting systems, and (3) cranking the engine with the starting equipment until ignition occurs and the engine is running.

The steps in the starting procedure will differ depending on whether the engine is being started after routine securing, after a brief period of idleness, or after a long period of idleness. We will first list the steps to follow after a routine securing.

STARTING PREPARATIONS AFTER ROUTINE SECURING

First, make ready the supporting systems—cooling, lubrication, and fuel:

1. Check all valves in the seawater cooling system to ensure that the system is lined up for normal operation.
2. Start separate motor-driven seawater pump, if provided. If an auxiliary engine is cooled from the ship's saltwater circulating system, ensure that adequate pressure and flow will be available.
3. Vent seawater coolers, using the vent cocks or vent valves on the heat exchanger shells. If this is not done, air or gas can accumulate, reducing the effective cooling surface area of a heat exchanger.
4. Check the level in the freshwater expansion tank. Remember that a cold expansion tank will need a lower fluid level than one that is hot, so leave room for expansion.

5. Check the freshwater cooling system: Set all valves in their operating positions, start the motor-driven circulating pump if provided, vent the system, and check freshwater level in the expansion tank again. The freshwater level may have dropped if air or gas was vented elsewhere in the system.

6. Check the lubricating system: Check oil level in the sump; add oil if necessary to bring it to the proper level. Ensure that adequate grease is applied to bearings that require grease lubrication. If oil heaters are installed, raise the lubricating oil to 100°F.

7. In idle engines the lube oil film can be lost from the cylinder wall; it is desirable to restore this film before actually starting the engine. (Large diesel engines will restore the film by pressurizing the lube oil system and jacking the engine over without starting it. The pressure in the lube oil system will oil the cylinders, and the pistons will distribute the oil film.) To pressurize the lubricating system either start the motor-driven lubricating oil pump, if installed, or operate a hand-operated lubricating oil pump. If the lubricating oil pump is driven by the engine, it will develop pressure when the engine is jacked over. (To reduce load on the jacking gear and prevent an accidental start, open any cylinder test valves or indicator cocks.) Then turn the engine over using the jacking gear, which may be motor-driven or hand-operated. As the engine turns over, observe the indicator cocks for excessive moisture which indicates water or fuel accumulation in the cylinders.

8. When you have performed the preceding operation, disengage the jacking gear and restore the valves and cocks to their operating positions.

9. Line up and prime the fuel systems. Check to ensure that there is sufficient clean fuel for the anticipated engine operation.

10. Check for malfunction in alarms, such as the low-pressure lubricating oil alarm and the freshwater high-temperature alarm.

11. Now start the engine with the starting system. Follow all proper procedures for the type of starting system in use.

12. Once the engine is running, energize the low-pressure lube oil alarm and the water temperature alarm. Pay careful attention to all gages and other indications of engine condition and performance. Diesel engines tend to be noisy, particularly when cold and idling. Familiarity with the normal sounds of the engine will help avoid unnecessary panic. Lubricating oil pressure is the best indication that a cold engine is operating properly. If it does not rise immediately to the operating pressure, STOP the engine and determine the cause of the low pressure.

13. If possible, avoid placing a load on the engine until it has reached operating temperatures. Loading a cold engine will produce carbon in the cylinder heads, cause excessive engine wear, and dilute the lubricating oil. The procedures for placing the engine on the line will depend on the type of installation, but in general, it is best to bring the engine up to speed gradually, while being very alert to signs of malfunction.

STARTING AFTER A BRIEF PERIOD OF IDLENESS

Starting a warm engine, after it was recently secured and if no unusual conditions are suspected, consists of (1) aligning the systems that may have been secured such as circulating water, (2) setting the engine to run in the desired direction, if a reversing engine is being restarted, (3) disconnecting the load, if possible, and (4) cranking the engine up to starting speed. Carefully observe lubricating oil pressure. The temperature of coolant may exceed normal operating temperatures for a minute or so until the heat accumulated in the secured engine is removed.

STARTING PREPARATIONS AFTER OVERHAUL OR LONG IDLE PERIOD

Additional checks and inspections should be made when the engine to be started has been idle for a long period of time or has been overhauled.

1. Inspect parts of the engine system that have been worked on to ensure: the work is

complete, covers have been replaced, and it is safe to operate any valves or equipment that has been tagged out of service.

2. Check all pipe connections to see whether the connections are tight and whether the systems have been properly connected.

3. Fill the freshwater cooling system with freshwater if it has been drained. Be sure coolant flows through all parts and components of the system. Vent the system. If possible, apply a hydrostatic test to the cooling system.

4. Make a thorough check of the lubricating system. Check sump level and fill if necessary. If a separate oil pump is installed, prime the engine. The system can be considered primed when a slight pressure is registered on the engine oil pressure gage. Then make a visual check, with inspection plates removed, to see whether oil is present at all points of the system and in each main bearing. Examine pipes and fittings for leaks. If lubricators are installed, be sure they are filled.

5. Inspect air receiver, filter, and the blower's discharge passages for cleanliness, and remove any oil accumulations.

6. If the engine has a hydraulic governor, inspect the governor oil level. If an overspeed trip is installed, be sure it is in proper operating condition and position.

7. Examine all moving parts of the engine to see that they are clear for running. Check the valve assemblies, including the intake, exhaust, and air-starting valves, for freedom of movement.

8. Check fuel injector timing.

9. Inspect the fuel oil service tank for the presence of water and sediment. Fill the tank with clean oil if necessary. Start auxiliary fuel pumps, if installed, and see whether fuel pressure gages are registering properly. Examine fuel oil piping and fittings for leaks, especially fittings and lines inside the engine. Thoroughly vent all air from the fuel system, using the vent cocks. Be sure that fuel oil strainers have been cleaned or that new filter elements have been installed. If fuel oil has been standing in the same tank, run it through a centrifuge to purify it.

10. If the engine has an air-starting system, open the lines on the system and blow them out. Reconnect these lines and pressurize the starting-air banks.

11. Make a final check to ensure that all parts are in place, then open all scavenging-air header and exhaust header manifold drains.

12. Now start the engine, using the procedures for a routinely secured engine.

NORMAL OPERATING PROCEDURES

Operation of a diesel engine cannot be separated from the operation of the equipment it is driving. Therefore, for purposes of our discussion, we shall assume that you, as the operator, are fully aware of the complete system you are running. Each type of engine and installation has its special operating routine. A systematic procedure has usually been established, based on these special requirements and on the experience of the engine operators with the particular installations. You must respect and follow this procedure. The following description of procedures is general and should be considered as incomplete in terms of operation of any specific plant.

While engines are operating, their performances are monitored and observed for two purposes: (1) to recognize early any unsatisfactory operation or impending malfunctions so that immediate casualty control procedures can be started and (2) to develop a comparative record over a period of time so that gradually deteriorating conditions can be detected. For the latter purpose, you must keep a complete log of all operating conditions. Observe and record the operating pressures and temperatures in the log at hourly intervals. Compare the entries over a period of time and note any deviations from normal conditions.

You must be alert to changed, or unusual, noises made by operating machinery. Gradually changing sounds are difficult to detect, especially if you are inexperienced. Often an oncoming watch will detect a new sound that the present watch was not aware of.

When unusual operating conditions occur, load, lubrication, cooling, engine speed, or fuel supply are usually responsible, either directly or indirectly.

Load

The manner of applying a load to an engine and the regulation of the load will depend on the type of load and system design. The procedures for loading an engine, or placing it on the line will be established by local doctrine, or in new installations by the system designers.

Whenever you are starting a cold engine, allow ample time to build the load up gradually. NEVER heavily load the engine until it is warmed up. The manufacturer's instructions should be followed in all but emergency situations. Gradual application of the load will prevent damage to the engine from such conditions as uneven rates of expansion and inadequate lubrication at low temperatures.

Never operate a diesel engine for prolonged periods with less than one-third of its rated load. Combustion at low load is incomplete, so partially burned fuel oil and lubricating oil may cause heavy carbon deposits which will foul the valve stems, piston rings, and exhaust systems. In addition to these problems, a low-load operation may cause the exhaust valves to stick and burn, dilute the lubricating oil, scuff the cylinder liners, increase fuel consumption, and cause excessive smoke when the load is increased. If you must operate an engine at less than 30% power for more than 30 minutes, you should increase the load to above 50% power at the first opportunity.

Diesel engines are designed to operate up to full-load conditions for prolonged periods, but should NEVER be operated at an overload except in an emergency. This includes both excessive torque and speed loads. Overload may be indicated by excessive temperatures, smoky exhaust, or excessive firing pressures. When conditions indicate an overload, reduce the load immediately.

Lubrication

We discussed the importance of lubrication in chapter 9. The performance of the lubrication system is one of the most important factors of engine operation which you can monitor. Indicators continuously show oil temperature and pressure in key parts of the system. While the engine is operating, you should monitor these indicators and sight glasses on a regular basis. An alarm of some sort will usually warn of low pressure but, if one is not installed, you must continuously monitor the oil pressure.

If the lubrication system uses a wet sump, you should check the level at regular intervals. Otherwise, observe the amount of oil in the system at regular intervals by the available means. Under typical operating conditions, you should be able to estimate the rate at which the engine burns its lubricating oil and to predict when replenishment will be needed.

The condition and cleanliness of the lubricating oil is critical for long engine life. If lubricating oil purifiers are provided, keep them running while the engines are running. When the engines are idle, operate the purifiers at regular intervals. Clear the metal-edge type lubricating oil strainers by rotating the cleaning handle two complete revolutions. This is done each watch. The condition of filters is often indicated by the amount of pressure drop from the inlet to outlet. Gages are installed to indicate this differential and you should check them frequently. Equipment is usually available to check viscosity and you should use it daily to test the lubricating oil to determine the percentage of fuel dilution.

Pressures and Temperatures

All pressures and temperatures must be maintained within the normal operating ranges; if this is not possible, secure the engine. Check all instruments frequently. The manufacturer's instructions provide detailed information concerning the proper operating pressures and temperatures. When this information is not available, maintain the temperature of the lubricating oil as it leaves the engines between 140° and 180°F, and maintain the temperature of the freshwater as it leaves the engine at no less than 140° or more than 170°F. Do not allow the temperatures in the saltwater cooling system to exceed 130°F; higher temperatures will cause deposits of salt and other solids in the coolers and piping and will aggravate corrosion. To ensure efficient operation in engines that are cooled by saltwater, never allow the temperature of the saltwater coolant to drop below 100°F at the engine discharge.

Make frequent checks of the cooling system to detect any leaks. Vent coolers and heat exchangers at least once each watch. Check the level of the freshwater in the expansion tank frequently; add freshwater as necessary. If the freshwater level gets low enough to cause overheating of the engine, NEVER add cold water until the engine has cooled.

Critical Speeds

The vibrations resulting from operation at destructive critical speeds will cause serious damage to an engine.

All moving parts of machinery have critical speeds. Critical speed means certain ranges of speed during which excessive vibration in the engine is created. Every part of the engine has a NATURAL PERIOD OF VIBRATION, or FREQUENCY. When impulses set up a vibration which coincides with the natural frequency of the body, each impulse adds to the magnitude of the previous vibration; finally, the vibration becomes great enough to damage the engine structure.

Vibration may be set up by linear impulses from reciprocating parts or by torsional impulses from rotating members. The crankshaft is the part which causes torsional vibrations. The pressure impulse on the piston puts a twist in the crankshaft; when the pressure on the piston is somewhat relieved, the shaft untwists. If pressure impulses which are timed to the natural period of the shaft, are permitted to continue, the amplitude of vibration will become so great that it might break the shaft. If the speed of such an engine is changed, however, the pressure impulses will no longer coincide with the natural period of the shaft; the vibration will then cease.

Since each engine has a natural period of vibration, which cannot be changed by the operator, the only control you have is to avoid operating the engine at critical speeds. If critical speeds exist below the normal speed of the engine, you must pass through the critical ranges as quickly as possible when changing engine speed. Detailed information concerning critical speed ranges is provided with each installation. Tachometers must be marked to show any critical speed ranges to make it easier for the operator to keep the engine out of the critical ranges. Tachometers sometimes get out of adjustment; therefore, they must be frequently checked with mechanical counters.

Fuel

You must maintain an adequate supply of the proper fuel. Check the fuel system frequently for leaks. Clean all fuel oil strainers at periodic intervals. Replace fuel oil filter elements whenever necessary. When diesel fuel oil purifiers are provided, purify all fuel before transferring it to the service tank. Frequently check the service tank for water and other settled impurities by sampling through the drain valve at the bottom of the tank. Drain off water and impurities.

Stopping and Securing Procedures

Diesel engines are stopped by shutting off the fuel supply—placing the throttle or the throttle control in the stop position. If the engine installation permits, it is a good idea to let the engine idle, without load, for a short time before stopping it to allow the engine temperatures to reduce gradually. It is also good practice to operate the overspeed trip, when stopping the engine, to check the operating condition of the device. Before tripping the overspeed trip, reduce the engine speed to low idling speed. Some overspeed trips reset automatically; in some installations, you must reset the overspeed trip manually before the engine can be started again.

In addition to the detailed procedures listed in checklists and manufacturer's manuals, you should take the following steps after an engine has stopped:

1. Open the drain cocks on the exhaust lines and those on the scavenging-air inlet headers, if provided.
2. Leave open an adequate number of indicator cocks, cylinder test valves, or hand-operated relief valves to indicate any water in the cylinders.
3. Secure the air pressure. If starting air is left on, the possibility of a serious accident exists.
4. Close all sea valves.
5. Allow the engine to cool.
6. Drain the freshwater when freezing temperatures prevail, unless an antifreeze solution is being used.
7. Clean the engine thoroughly by wiping it down before it cools. Clean the deck plates and see that the bilges are dry.
8. Arrange to have any casualties repaired. No matter how minor they may appear, repairs must be made and troubles must be corrected promptly.

PRECAUTIONS IN OPERATING DIESEL ENGINES

You must obtain the specific safety precautions for a given engine from its manufacturer's operating instructions. In addition to those of the manufacturer, you should observe the following precautions in operating and maintaining a diesel engine.

RELIEF VALVES

If a relief valve on an engine cylinder lifts (pops) several times, stop the engine immediately and determine and remedy the cause of the trouble. NEVER lock relief valves in a closed position, except in an emergency. Pressure-relief mechanisms are fitted on all enclosures in which excessive pressures may develop. Strict compliance with designated adjustments on these mechanisms is essential.

FUEL

Precautions must be taken to ensure that fuel is NOT pumped into a cylinder while valves are being tested or while the engine is being motored, since an excessive pressure may be created in the cylinders when combustion of the fuel takes place. When fuel reaches the injection system, it should be absolutely free of water and foreign matter. You must thoroughly centrifuge the fuel before use and keep the filters clean and intact. Fuel oil leakage into the lubricating oil system will cause dilution of the lubricating oil with consequent reduction in viscosity and lubricating properties.

COOLING WATER

Do NOT allow a large amount of cold water, under any circumstances, to enter a hot engine suddenly. Rapid cooling may crack a cylinder liner and head or seize a piston. Stop the engine when the volume of circulating water cannot be increased and the temperatures are too high. In freezing weather, you must carefully drain all spaces which contain freshwater and which are subject to freezing, unless an antifreeze solution is added to the water.

STARTING AIR

When engines are stopped, you must vent all starting air lines; serious accidents may result if pressure is left on. Intake air must be kept as clean as possible; accordingly, you must keep all air ducts and passages clean.

CLEANLINESS

Cleanliness is one of the basic essentials in the efficient operation and maintenance of diesel engines. You must maintain clean fuel, clean air, clean coolants, clean lubricants, and clean combustion. You must keep the engines clean at all times, and take steps to prevent oil from accumulating in the bilges or in other pockets.

EMERGENCY DIESEL GENERATORS

Practically all naval ships are equipped with diesel-driven emergency generators. (Diesel engines are most suitable for this application because of their self-sufficiency and quick-starting ability.) Emergency generators furnish power directly to the electrical auxiliaries, radio, radar, weapons, and vital machinery spaces. In addition, emergency generators serve as a source of power for casualty power installations. All engineering personnel should become familiar with the emergency system aboard their ship.

The typical shipboard plant consists of two emergency diesel generators, one forward and one aft, in spaces outside the enginerooms and firerooms. Each emergency generator has its individual switchboard and switching arrangement for control of the generator and for distribution of power to certain vital auxiliaries and to a minimum number of lighting fixtures in vital spaces.

The capacity of the emergency unit varies with the size of the ship in which it is installed. Regardless of the size of the installation, the principle of operation is the same.

Emergency diesel engines are started either by compressed air or by a starting motor and develop full rated load power within 10 seconds. In a typical installation, the starting mechanism is actuated when the ship's supply voltage on the bus falls to approximately 80% of normal. In a 440-volt system, this would be approximately 350 volts. The generators are not designed for parallel operation. Therefore, when the ship's supply voltage fails, a transfer switch automatically disconnects the emergency switchboard from the main distribution switchboard and connects the emergency generator to the emergency switchboard. With this arrangement, transfer from the emergency switchboard back to the main distribution switchboard is accomplished manually; then, the emergency generator must be manually stopped and reset for automatic starting.

Since the emergency diesel generators are of limited capacity, only certain circuits can be supplied from the emergency bus. These include such circuits as the steering gear and the interior communication switchboard. If some vital circuit is secured, another circuit may then be cut in, up to the capacity of the generator.

OPERATING INSTRUCTIONS

Normally, the emergency diesel generator will start automatically, but for test purposes and under other conditions it may be started and operated manually. The following are the principal points for the operation of an air-started diesel generator:

The engine is started automatically when the ship's supply current fails and causes the solenoid air valve (located between the starting air tank and the engine) to open, admitting starting air to the engine. The engine then turns over on air until firing begins. As the engine speed increases, the air cutoff governor valve closes and shuts off the starting air. As soon as the normal operating speed is reached and the generator develops normal voltage, the solenoid air valve also closes to shut off the starting air supply. (The starting air tank is charged from the high-pressure air system, through a reducing valve. The pressure carried in the starting air tank varies from 300 to 600 psi, depending on the installation.)

To start the engine manually, deenergize the solenoid valve. If the ship's supply current is not broken, you must open the switch in the solenoid circuit. Then admit starting air to the engine by opening the valve manually with the handwheel. After firing begins, turn the handwheel to close the valve and cut off the starting air. (The handwheel must be turned to the open position of the valve whenever it is desired to leave the generator set available for emergency service.)

If the lubricating oil pressure does not build up immediately after the engine starts, shut down the engine and determine the cause of the trouble. NEVER operate the engine without lubricating oil pressure. At regular intervals, check the lube oil pressure, fuel pressure, cooling water temperature, and exhaust temperature. (In addition, clean the fuel oil and lubricating oil filters regularly.)

To SHUT DOWN or STOP the engine, hold the fuel-control lever to the STOP position. After the lever is released, it automatically returns to the running position to permit the engine to be restarted.

OPERATING PRECAUTIONS

You must observe the following operating precautions:

1. Do NOT operate the engine without lubricating oil pressure; this will cause serious damage.
2. Do NOT operate the engine in overloaded or unbalanced condition. Overload condition on one or more cylinders may be indicated by an increase in the exhaust temperature or by smoky exhaust.
3. Do NOT operate the engine with an abnormal water outlet temperature.
4. Do NOT operate the engine after an unusual noise develops; the noise might be an indication of pending trouble. Investigate the noise and correct any trouble, particularly if it may prove harmful to the engine.
5. If there is danger of freezing during shutdown periods, drain all water jackets.
6. If the overspeed device trips and shuts down the engine, investigate the cause of the trouble before restarting the engine.
7. Make certain that the fittings of the ventilation system, serving the compartment in which the engine is located, are open. (If the diesel engine were started while the vent system is secured, the engine would expend the air in the compartment; under such conditions the engine may continue to operate long enough to suffocate you. This applies to the installations where the engine does not have a direct air supply from the outside to the intake manifold.) THESE PRECAUTIONS ALSO APPLY TO EMERGENCY DIESEL FIRE PUMPS.

FACTORS INFLUENCING CASUALTY CONTROL

Engineering casualty control is much broader than the immediate actions taken at the time of the casualty. Engineering casualty control reaches its peak efficiency by combining sound design, careful inspection, thorough plant maintenance (including preventive maintenance), and effective personnel organization and training. CASUALTY PREVENTION IS THE MOST EFFECTIVE FORM OF CASUALTY CONTROL.

DESIGN OF CASUALTY CONTROL

Sound design influences the effectiveness of casualty control in two ways: (1) it eliminates weaknesses which may lead to material failure, and (2) it installs alternate or standby means for supplying vital services in the event of a casualty to the primary means. Both of these factors are considered in the design of naval ships. Individual plants aboard ship are equipped with duplicate vital auxiliaries, loop systems, and cross connections. Complete propulsion plants are designed to operate as isolated units (split-plant design).

CASUALTY CONTROL COMMUNICATIONS

Casualty control communication is vitally important to the operation and organization of the ship. Without adequate and proper means of communication between the different units, the whole organization of casualty control will fail in its primary objective.

To ensure that sufficient means of communication are available, several different systems are installed aboard ship. The normal means of communications are the battle telephone circuits (sound-powered), interstation 2-way systems (intercoms), ship's service telephones, ship's loudspeaker (1-MC), and voice tubes. Messengers are used in some situations when the above methods of communication are not available or when written reports are required.

Transmission of correct information regarding a casualty and the speed with which the report is made are the principal values of any method of communication.

Control of all communication circuits must be established by the control station. The circuits must never be allowed to get out of control due to "cross talk" caused by more than one station. Casualty control communication must be incorporated into casualty control training. The control station or engineering control must be promptly notified of a casualty to prevent other casualties which could be more serious than the original casualty.

INSPECTION AND MAINTENANCE

Inspection and maintenance are vital to successful casualty control; they minimize casualties caused by material failures. Continuous and detailed inspection procedures discover partly damaged parts, which may fail at a critical time, and also eliminate the underlying conditions, which lead to early failure (maladjustment, improper lubrication, corrosion, erosion, and other causes of machinery damage). You must pay particular and continuous attention to the following symptoms of malfunctioning:

1. Unusual noises
2. Vibrations
3. Abnormal temperatures
4. Abnormal pressures
5. Abnormal operating speeds

You must thoroughly familiarize yourself with the specific temperatures, pressures, and operating speeds of equipment required for normal operation, so that you will detect any departure from normal operation.

If a gage or other instrument for recording operating conditions of machinery gives an abnormal reading, you must fully investigate the cause. The installation of a spare instrument or a calibration test will quickly indicate whether the abnormal reading is due to instrument error. You must trace any other cause to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external evidence is readily apparent. You should be suspicious of any changes in the operating speeds (those normal for the existing load) of pressure-governor-controlled equipment. Variations from normal pressures, lubricating oil temperatures, and system pressures indicate either inefficient operation or poor condition of machinery.

When a material failure occurs in any unit, promptly inspect all similar units to determine whether there is any danger that a similar failure might occur. Prompt inspection may eliminate a wave of repeated casualties.

Pay strict attention to the proper lubrication of all equipment, including frequent inspection and sampling to determine that the correct quantity of the proper lubricant is in the unit. It is good practice to make a daily check of samples of lubricating oil in all auxiliaries. Allow samples to stand long enough for any water to settle. When auxiliaries have been idle for several hours, particularly overnight, drain a sufficient sample from the lowest part of the oil sump to remove all settled water. Replenish with fresh oil to the normal level.

To detect saltwater in the oil, draw off the settled water with a pipette and run a standard chloride test. To obtain a sample of sufficient size for test purposes, add distilled water to the oil sample, shake it vigorously, and allow the water to settle before draining off the test sample. Because of its corrosive effects, saltwater in the lubricating oil is far more dangerous to a unit than an equal quantity of freshwater. Saltwater is particularly harmful in units containing oil-lubricated ball bearings.

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TRAINING

Casualty control training must be a continuous step-by-step procedure with constant refresher drills. Realistic simulation of casualties requires adequate preparation. The amount of advance preparation required is not always readily apparent. You must carefully visualize the full consequences of any error that could be made in handling simulated casualties which were originally intended to be of relatively minor nature. There must be a complete analysis and all participants must be carefully instructed before simulation of major casualties and battle damage. A new crew must have an opportunity to become familiar with the ship's piping systems and equipment before simulation of any casualty which may have other than purely local effects.

In the preliminary phases of training, a "dry run" is useful for imparting knowledge of casualty control procedures without endangering the ship's equipment by too realistic simulation of a casualty. Under this procedure, a casualty is announced, and all individuals are required to report as though action were taken (an indication must be made that the action is simulated). Definite corrective actions can be taken, and with careful supervision the timing of individual actions can appear to be very realistic. Regardless of the state of training, such dry runs should always be held before actual simulation of any involved casualty. Similar rehearsals should be held before simulation of relatively simple casualties whenever an appreciable proportion of personnel involved are new to the ship and, particularly, after an interruption (such as occasioned by periods of naval shipyard overhauls) of regularly conducted casualty training.

CORRECTION AND PREVENTION OF CASUALTIES

The speed with which corrective action is applied to an engineering casualty is often of paramount importance. This is particularly true in dealing with casualties which affect the propulsion power, steering, and electrical power generation and distribution. If casualties associated with these functions are allowed to accumulate, they may lead to serious damage to the engineering installation–damage which often cannot be repaired without loss of the ship's operating availability. When risk of possible permanent damage exists, the commanding officer has the responsibility of deciding whether to continue operation of equipment under casualty conditions; such action can be justified only when the risk of even greater damage, or loss of the ship, may be incurred by immediately securing the affected unit.

To reemphasize, whenever there is no probability of greater risk, the proper procedure is to secure the malfunctioning unit as quickly as possible even though considerable disturbance to the ship's operations may occur. Although speed in controlling a casualty is essential, action should never be undertaken without accurate information; otherwise, the casualty may be mishandled, and irreparable damage and possible loss of the ship may result. War experience has shown that the cross-connecting of intact systems with a partly damaged one must be delayed until it is certain that such action will not jeopardize the intact systems. Speed in handling casualties can be achieved only by thorough knowledge of the equipment and associated systems and by thorough and repeated training in the routine required to handle specific predictable casualties.

PHASES OF CASUALTY CONTROL

The handling of any casualty can usually be divided into three phases: limitation of the effects of the damage, emergency restoration, and complete repair.

The first phase is concerned with immediate control of a casualty to prevent further damage to the unit concerned and to prevent the casualty from spreading through secondary effects.

The second phase consists of restoring, as far as practicable, the services which were interrupted as a result of a casualty. For many casualties, the completion of this phase eliminates all operational handicaps, except for the temporary loss of standby units which lessens ability to withstand further failure. If no damage to, or failure of, machinery has occured, this phase usually completes the operation.

The third phase of casualty control consists of making repairs which will completely restore the installation to its original condition.

SPLIT-PLANT OPERATION

In ships having two or more shafts, a fundamental principle of engineering casualty control is split-plant operation. The purpose of split-plant design is to minimize the damage that might result from one hit.

Most naval ships built primarily as warships have at least two engineering plants. The larger combatant ships have four individual engineering plants.

Split-plant operation means dividing the engines, pumps, and other machinery so that two or more engineering plants are available, each complete in itself. Each main engine installation has its own piping systems and other auxiliaries. Each engineering plant operates its own propeller shaft. If one engineering plant were put out of action by explosion, shellfire, or flooding, the other plant could continue to drive the ship ahead, though at somewhat reduced speed.

Split-plant operation is not absolute insurance against damage that might immobilize the entire engineering plant, but it does reduce the chances of such a casualty. It prevents transmission of damage from one plant to another or possible serious effect on the operation of the other plant or plants. It is the first step in the PREVENTION of major engineering casualties.

The fuel oil system is generally so arranged that fuel oil transfer pumps can take suction from any fuel oil tank in the ship, and oil can be pumped to any other fuel oil tank. Fuel oil service pumps supply oil from the service tanks to the main engines. In split-plant operations the forward fuel oil service pumps of a ship are lined up with the forward service tanks, and the after service pumps are lined up with the after service tanks. The cross-connection valves in the fuel oil transfer line must be closed except when oil is being transferred.

Geared diesel propulsion plants are designed for split-plant operation only; however, some of the auxiliary and main systems may be run cross-connected or split. Among these auxiliaries are the starting air systems, cooling water systems, firemain systems and, in some plants, the fuel and lube oil systems.

In diesel-electric installations the diesel elements are split, but generator elements can be run split or cross-connected. The advantages of this type of installation will depend on operating procedures as well as design.

LOCKING MAIN SHAFT

An engineering casualty may be such that rotation of the main shaft will cause further damage. The main shaft should be locked until necessary repairs can be made since, except at very low speeds, movement of the ship through the water will cause the shaft to turn, whether the ship is proceeding by its own power or being towed.

For locking a main shaft, there are no standard procedures applicable to all types of diesel-driven ships. For ships that have main reduction gears, shaft locking by means of the jacking gear is permissible, if it is designed for this purpose as indicated by the manufacturer's instructions or with NAVSEA approval. Some ships have brakes that are used for holding the shaft stationary. If no provision has been made for locking the main shaft, it is usually possible to arrange a jury rig, preferably at a flanged coupling, which will hold the shaft. As a precautionary measure, it is best to make up jury rigs in advance of an actual need for locking a shaft. On diesel-electric drive ships, no attempt should be made to hold the shaft stationary by energizing the electrical propulsion circuits.

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EMERGENCY PROCEDURES

Under certain circumstances you may receive the order to start additional engines. Time may not permit following normal routine procedures; you may need to use emergency procedures. Because these procedures will differ, depending on the installation, you must be familiar with the procedures established for your ship.

The emergency procedures are available in the *Engineering Casualty Control Manual* for your ship. Manuals of this type are prepared and issued by type commanders. Upon receipt, manuals are modified to fit the individual installation. It is the responsibility of your ship's engineer officer to establish the step-by-step procedures and the necessary checklists which are to be followed when routine procedures will require too much time.

ENGINEROOM CASUALTIES

For each class of ship, the type commander formulates engineering casualty procedures which apply to the specific type of engineering plant.

In the event of a casualty to a component of the propulsion plant, the principal objective is to prevent additional or major casualties. Where practicable, the propulsion plant should be kept in operation by means of standby pumps, auxiliary machinery, and piping systems. The important thing is to prevent minor casualties from becoming major casualties, even if it means suspending the operation of the propulsion plant. It is better to stop the main engines for a few minutes than to risk putting them completely out of commission, requiring time for major repairs to place them back into operation.

When a casualty occurs, the engineering officer of the watch and the petty officer of the watch must be notified immediately. The watch officer notifies the OOD and engineer officer. Main engine control must keep the bridge informed as to the nature of the casualty, the ship's ability to answer bells, the maximum speed available, and the probable duration of the casualty.

DIESEL ENGINE CASUALTIES

The operator's duties concerning engineering casualties and their control will depend on the type of ship, which may be anything from a patrol boat to a carrier. The operator will operate engines of various sizes, made by various manufacturers and intended for different types of services.

Obtain detailed information on diesel engine casualty control procedures from the manufacturer's instructions, pertinent type commander's instructions, the ship's *Engineering Casualty Control Manual*, and the *Engineering Operational Casualty Control (EOCC).*

Safety Precautions–General

In addition to following the specific safety precautions listed in the operating instructions for an engine, you must continuously exercise good judgment and common sense in taking steps to prevent damage to material and injury to personnel.

In general, you can help to prevent damage to machinery by operating engines according to prescribed instructions; by observing all rules of cleanliness when handling the parts of an engine during maintenance or overhaul; by having a thorough knowledge of your duties; and by being totally familiar with the parts and functions of the machinery you are operating and maintaining. Damage to a launch or boat may be prevented by maintaining machinery so that the engines will be ready for service at full power in the event of an emergency and by taking steps to prevent conditions which are likely to constitute fire or explosion hazards.

Personnel work most safely when they thoroughly know how to perform their duties, how to use their tools and machines, how to take reasonable precautions around moving parts, and when they are consistently careful and thoughtful in performing their duties.

Emergency Starting and Securing

There may be times when an engine must be started, operated, or secured under emergency conditions. Before this becomes necessary, operating personnel should learn the procedures in the ship's *Engineering Casualty Control Manual.* It is also wise to have these procedures posted near the engine operating position or otherwise easily accessible. Operators should be drilled in casualty control procedures at regular intervals.

There is a definite hazard to starting a diesel engine under emergency conditions in that personnel are rushed and tend to be careless. There is always time to ensure that personnel are clear of external moving parts, such as belt drives and shafts, before actuating the starting gear. If emergency repairs have been made, be sure that all tools are accounted for before closing up the engine and that all essential parts have been replaced before starting the engine. An engine can be started and run briefly if it has air and fuel, and if the starting system will operate. It will run much longer if it has lubrication and a functional cooling system. With the exception of some boat engines that can be started by towing the boat, there is no backup for the starting system. Usually, sufficient spares and resources are available to restore any casualty to the starting system, but again, if the repair is rushed, the danger of careless work will increase.

In an emergency an engine may be started by lining up the fuel system and actuating the starter. Before this is done, be sure that there is a supply of air to the engine and engine compartment and that the lubricating system will operate. After starting, establish cooling water flow and review all the normal prestarting checks as quickly as possible.

If an operating engine suffers a casualty, the decision of whether to continue operating or to secure the unit must be made immediately. The condition of the ship's operation is an important factor in this decision. In some instances, when risk of possible permanent damage exists, the commanding officer has responsibility for deciding whether to continue operation of equipment under casualty conditions. Such action can only be justified when the risk of greater damage, or loss of the ship, may be incurred by securing the affected unit. Risk to the ship is present in actual combat situations, severe weather conditions, narrow channels, and potential collision situations which include close-formation steaming.

Engines can be operated with casualties to vital auxiliaries if the function of the auxiliary unit can be produced by other means. For instance, cooling water flow can be reestablished from a firemain, and an engine can operate for some time with saltwater in its cooling system if it is well rinsed afterward.

If the decision is made to secure an engine that has suffered a casualty, the general rule is to stop it as soon as possible. In the case of a propulsion engine, it will usually be necessary to stop the shaft also. This may require slowing the ship until the shaft is stopped and locked with the turning gear, shaft brake, or other means.

Engines can almost always be stopped by securing the flow of fuel. Occasionally, this does not work, since a blower seal leak or similar source permits the engine to run on its own lubricating oil. If the engine cannot be braked to a stop or stilled by increasing the load on it, some means must be found to stop the airflow to it. Discharging a CO_2 extinguisher into the air intake is effective, or the air intake can be covered by some means. If the latter is done, be sure the covering will not be sucked into the blower, causing an additional casualty.

OPERATING INSTRUCTIONS AND SAFETY PRECAUTIONS

A master list of all the engineering department operating instructions and safety precautions is kept in the log room. When a ship is commissioned, the building yard normally provides a master copy in addition to posting the individual operating instructions and safety precautions throughout the engineering spaces. If any of the posted operating instructions and safety precautions are damaged or lost, a duplicate copy can be readily made up from the master list.

For ships in commission and in service, plastic laminated operating instructions and safety precautions are available and are listed in the *Navy Stock List of Forms and Publications,* NAVSUP Publication 2002.

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CHAPTER 13

TROUBLESHOOTING

The procedures for troubleshooting internal-combustion engines are somewhat similar for both diesel and gasoline engines. In many instances, the information which follows will apply to both types of engine. However, we shall also discuss principal differences. Since most of the internal-combustion engines used by the Navy are diesel, we shall deal primarily with this type of engine.

This chapter is concerned with troubles both in starting an engine and after an engine is started. The troubles we shall discuss are chiefly the kind that can be corrected without major overhaul or repair and those that can be identified by erratic operation of the engine, or warnings by instruments, or inspection of the engine parts and systems. There is also a section devoted to those systems of the gasoline engine which are basically different from those of the diesel engine.

Keep in mind that the troubles listed here are general and may or may not apply to a particular diesel engine. When working with a specific engine, check the manufacturer's technical manual and any instructions issued by the Naval Sea Systems Command.

THE TROUBLESHOOTER

Complete failure of a power plant at a crucial moment may imperil both ship and crew. Even comparatively minor engine trouble, if not recognized and corrected as soon as possible, may develop into a major breakdown. Therefore, you, as an operator of internal-combustion engines, must train to be a successful troubleshooter.

It may happen that an engine will continue to operate even when a serious casualty is imminent. However, if troubles are impending, symptoms are usually present. Your success as a troubleshooter depends partially upon ability to recognize these symptoms when they occur. You will use most of your senses to detect trouble symptoms. You may see, hear, smell, or feel the warning of trouble to come. Of course, common sense is also a requisite. Another factor in your success as a troubleshooter is your ability to locate the trouble after once deciding something is wrong with the equipment. Then you must be able to determine as rapidly as possible what corrective action to take. In learning to recognize and locate engine troubles, experience is the best teacher.

Instruments play an important part in detecting engine troubles. You should read the instruments and record their indications regularly. If the recorded indications vary radically from those specified by engine operating instructions, it is a warning that the engine is not operating properly and that some type of corrective action must be taken. You must be familiar with the specifications in the engine operating instructions, especially those pertaining to temperatures, pressures, and speeds. When instrument indications vary considerably from the specified values, you should know the probable effect on the engine. When variations occur in instrument indications, before taking any corrective action, you should be sure that such variations are not the fault of the instrument. Instruments should be checked immediately when they are suspected of being inaccurate.

Periodic inspections are also essential in detecting engine troubles. Such inspections will reveal failure of visible parts, presence of smoke, or leakage of oil, fuel, or water. Cleanliness is probably one of the greatest aids in detecting leakage.

When an engine is secured because of trouble, the procedure for repairing the casualty follows an established pattern, if the trouble has been diagnosed. If you do not know the location of the trouble, find it. To inspect every part of an engine whenever a trouble occurs would be an almost endless task. You can find the cause of a trouble much more quickly by following a systematic and logical method of inspection. Generally speaking, a well-trained troubleshooter can isolate a trouble by identifying it with one of the engine systems. Once you have associated the trouble with a particular system, the next step is to trace out the system until you find the cause of the trouble. Troubles generally originate in only one system, but remember that troubles in one system may cause damage to another system or to component engine parts. When a casualty involves more than one system of the engine, trace each system separately and make corrections as necessary. It is obvious that you must know the construction, function, and operation of the various systems as well as the parts of each system for a specific engine before you can satisfactorily locate and remedy troubles.

Even though there are many troubles which may affect the operation of a diesel engine, satisfactory performance depends primarily on sufficiently high compression pressure and injection of the right amount of fuel at the proper time. Proper compression depends basically on the pistons, piston rings, and valve gear, while the right amount of fuel obviously depends on the fuel injectors and actuating mechanism. Such troubles as lack of engine power, unusual or erratic operation, and excessive vibration may be caused by either insufficient compression or faulty injector action.

You can avoid many troubles by following the prescribed instructions for starting and operating the engine. The troubles discussed in the following sections do not comprise a complete list, nor do all of these troubles necessarily apply to all diesel engines because of differences in design. Specific information on troubleshooting for all the diesel engines used by the Navy would require more space than is available here.

Even though a successful troubleshooter generally associates a trouble with a particular system or assembly, the troubles we discuss will be according to when they might be encountered, either before or after the engine starts. The troubles are indicative of the system to which they apply. Therefore, further identification is unnecessary.

ENGINE FAILS TO START

In general, the troubles that prevent an engine from starting can be grouped as follows: (1) the engine can neither be cranked nor barred over, (2) the engine cannot be cranked, but it can be barred over, and (3) the engine can be cranked, but it still fails to start. Figure 13-1 illustrates various conditions which commonly cause difficulties in cranking, jacking over, or starting the engine.

ENGINE CANNOT BE CRANKED NOR BARRED OVER

Most prestarting instructions for large engines require you to turn the crankshaft one or more revolutions before applying starting power. If the crankshaft cannot be turned over, check the turning gear to be sure that it is properly engaged. If the turning gear is properly engaged and the crankshaft still fails to turn over, check to see whether the cylinder test valves or indicator valves are closed and are holding water or oil in the cylinder. When the turning gear operates properly and the cylinder

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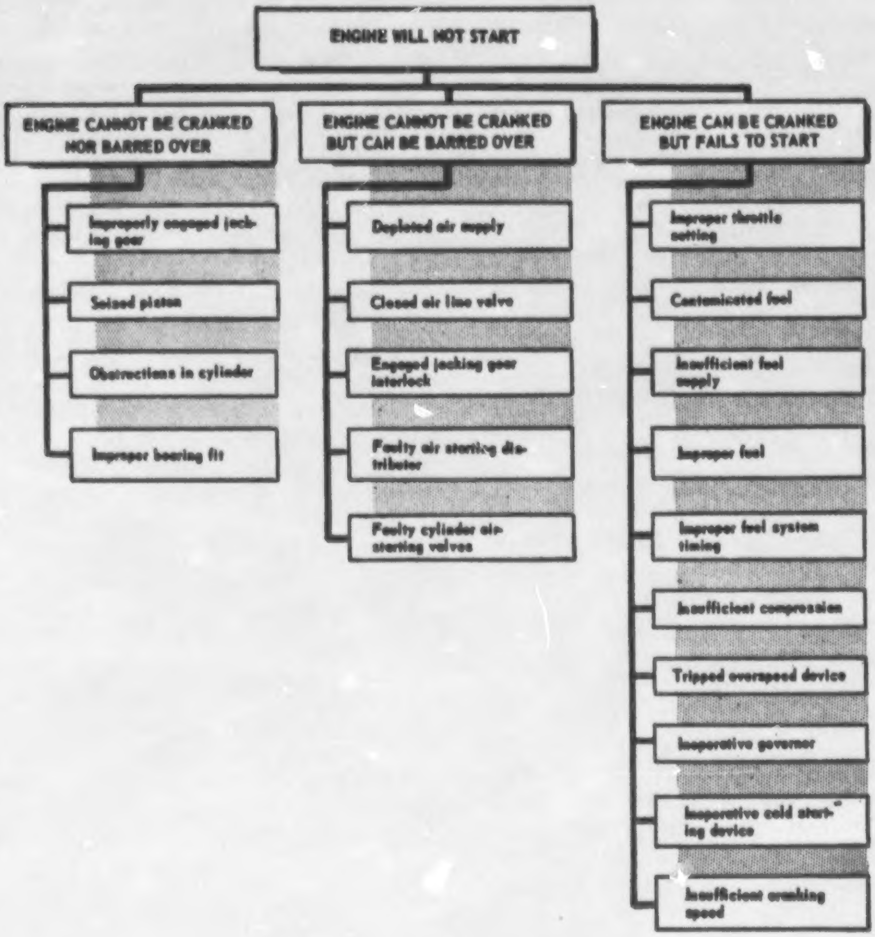
ENGINE WILL NOT START
ENGINE CANNOT BE CRANKED NOR BARRED OVER
ENGINE CANNOT BE CRANKED BUT CAN BE BARRED OVER
ENGINE CAN BE CRANKED BUT FAILS TO START
Improperly engaged jacking gear
Seized piston
Obstructions in cylinder
Improper bearing fit
Depleted air supply
Closed air line valve
Engaged jacking gear interlock
Faulty air starting distributor
Faulty cylinder air-starting valves
Improper throttle setting
Contaminated fuel
Insufficient fuel supply
Improper fuel
Improper fuel system timing
Insufficient compression
Tripped overspeed device
Inoperative governor
Inoperative cold starting device
Insufficient cranking speed

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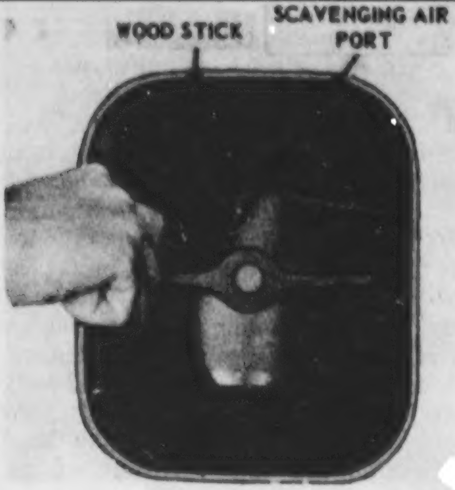
Figure 13-1.—Troubles which may prevent a diesel engine from starting.

test valves are open, but the engine nevertheless cannot be cranked or barred over, the source of the trouble will probably be of a much more serious nature. A piston or other part may be seized or a bearing may be fitting too tightly. Sometimes you may need to remove a part of an assembly to remedy the difficulty.

Some engines have ports through which pistons can be inspected. If inspection reveals that the piston is defective, remove the assembly. Figure 13-2 illustrates testing for stuck piston rings through the scavenging-air port.

If the condition of an engine without cylinder ports indicates that a piston inspection is required, you must take the whole assembly out of the cylinder.

Engine bearings must be carefully fitted or installed according to the manufacturer's instructions. When an engine cannot be jacked over because of an improperly fitted bearing, someone probably failed to follow instructions when the unit was being reassembled.



75.237X
Figure 13-2.—Checking the condition of the piston rings.

ENGINE CANNOT BE CRANKED BUT CAN BE BARRED OVER

You can trace most of the troubles that prevent an engine from cranking, but not serious enough to prevent barring over, to the starting system although other factors may prevent an engine from cranking. Only troubles related to starting systems are identified in this chapter.

If an engine fails to crank when you apply starting power, first check the turning or jacking gear to be sure that it is disengaged. If this gear is not the source of trouble, then the trouble is probably with the starting system.

AIR STARTING SYSTEM MALFUNCTIONS

Although the design of air starting systems may vary, the function remains the same. In general, such systems must have a source of air such as the compressor or the ship's air system; a storage tank; air flask(s); an air timing mechanism; and a valve in the engine cylinder to admit the air during starting and to seal the cylinder while the engine is running.

Defect In Timing Mechanism

All air starting systems have a unit which admits starting air to the proper cylinder at the proper time. The type of unit as well as its name–timer, distributor, air starting pilot valve, air starting distributor, or air distributor–may vary from one system to another. The types of air timing mechanisms are the direct mechanical lift, the rotary distributor, and the plunger type distributor valve. The timing mechanism of an air starting system is relatively trouble free except as noted in the following situations.

DIRECT MECHANICAL LIFT.–The operation of the direct mechanical lift air timing mechanism involves the use of cams, push rods, and rocker arms. The parts in the mechanism are subject to failure similar to that occurring in corresponding major engine parts. Therefore, you can find the causes of trouble in the actuating gear and the necessary maintenance procedures under information covering similar parts of the major engine systems.

Most troubles are a result of improper adjustment. Generally, this involves the lift of the starting air cam or the timing of the air starting valve. The starting air cam must lift the air starting valve enough to give a proper clearance between the cam and cam valve follower when the engine is running. If there is not enough clearance between these two parts, hot gases will flow between the valve and the valve seat, causing excessive heating of the parts. Since the starting air cam regulates the opening of the air starting valve, check those with adjustable cam lobes frequently to ensure that the adjusting screws are tight.

Obtain the proper values for lift, tappet clearance, and time of valve opening for a direct mechanical lift timing mechanism from the manufacturer's technical manual for the particular engine. Make adjustments only as specified.

ROTARY DISTRIBUTOR.–The rotary distributor timing mechanism requires a minimum of maintenance, but there may be times when the unit will become inoperative and you will need to disassemble and inspect it. Generally, the difficulty is caused by a scored rotor, a broken spring, or improper timing.

Since foreign particles in the air can cause scoring of the rotor, which results in excessive air leakage, you must keep the air supply as clean as possible. Another cause of scoring is lack of lubrication. If the rotor in a hand-oiled system becomes scored because of insufficient lubrication, the equipment could be at fault, or lubrication instructions may not have been followed. In either a hand-oiled or a pressure-lubricated system, check the piping and the passages to see that they are open. When scoring is not too serious, lap the rotor and body together. Use a thin coat of prussian blue to determine whether the rotor contacts the distributor body.

A broken spring may be the cause of an inoperative timing mechanism if a coil spring is used to maintain the rotor seal. If the spring is broken, replace it to ensure an effective seal.

An improperly timed rotary distributor will prevent an engine from cranking. Check the timing by information given in the instructions for the specific engine.

PLUNGER TYPE DISTRIBUTOR VALVE.–In a plunger tvpe distributor valve timing mechanism, the valve requires little attention; however, it may stick occasionally and prevent proper functioning of the air starting system. On some engine installations, the pilot air valve of the distributor may not open, while on other installations this valve may not close. The trouble may be caused by dirt and gum deposits, broken return springs, or lack of lubrication. Deposits and lack of lubrication will cause the unit valve plungers to bind and stick in the guides, while a broken valve return spring prevents the plunger from following the cam profile. Disassemble and thoroughly clean a distributor valve that sticks; replace any broken springs.

Faulty Air Starting Valves

Air starting valves admit starting air into the engine cylinder and then seal the cylinder while the engine is running. These valves may be pressure-actuated or mechanical lift type.

PRESSURE-ACTUATED VALVES.–In a pressure-actuated valve, the principal trouble encountered is sticking. The valve may stick open for a number of reasons. A gummy or resinous deposit may cause the upper and lower pistons to stick to the cylinders. (This deposit is formed by the oil and condensate which may be carried into the actuating cylinders and lower cylinders. Oil is necessary in the cylinders to provide lubrication and to act as a seal; however, moisture should be eliminated.) You can prevent this resinous deposit from forming by draining the system storage tanks and water traps as specified in the operating instruction. The deposit on the lower piston may be greater than that in the actuating cylinder because of the heat and combustion gases which add to the formation if the valve remains open. When the upper piston is the source of trouble, you can usually relieve the sticking, without removing the valve, by using light oil or diesel fuel and working the valve up and down. When using this method, be sure that the valve surfaces are not burned or deformed. If this method does not relieve the sticking condition, you will need to remove, disassemble, and clean the valve.

Pressure-actuated starting valves sometimes fail to operate because of broken or weak valve return springs. Replacement is generally the only solution to this condition; however, some valves are constructed with a means of adjusting spring tension. In such valves, increasing the spring tension may eliminate the trouble.

Occasionally the actuating pressure of a valve will not release, and the valve will stick open or be sluggish in closing. The cause is usually clogged or restricted air passages. Combustion gases will enter the air passageways, burning the valve surfaces; these burned surfaces usually must be reconditioned before they will maintain a tight seal. Keeping the air passages open will eliminate extra maintenance work on the valve surfaces.

MECHANICAL LIFT VALVES.–The mechanical lift type air starting valve is subject to leakage which, in general, is caused when the valve sticks open. Any air starting valve that sticks or leaks creates a condition which makes an engine hard to start. If the leakage in the air starting valve is excessive, the resulting loss in pressure may be sufficient to prevent starting.

Leakage in this type valve can be caused by an overtightened packing nut. The packing nut is sometimes overtightened to stop minor leaks around the valve stem when starting pressure is applied, but it may prevent seating of the air valve. As in the pressure-actuated valve, there may not be enough return spring tension to return the valve to the valve seat after admitting the air charge. If this occurs, gases from the cylinder will leak into the valve while the engine is running.

Obstructions such as particles of carbon between the valve and valve seat will hold the valve open, permitting combustion gases to pass. A valve stem bent by careless handling during installation may also prevent a valve from closing properly.

If a valve hangs open for any of these reasons, hot combustion gases will leak past the valve and valve seat. The gases burn the valve and seat and may cause a leak between these two surfaces even though the original causes of the sticking are eliminated.

Completely disassemble and inspect a leaking valve. It is subject to a resinous deposit similar to that found in a pressure-actuated air valve. Use a specified cleaning compound to remove the deposit. Be sure the valve stem is not bent. Check the valve and valve seat surfaces carefully. Eliminate scoring or discoloration by lapping with a fine lapping compound. You may use jewelers' rouge or talcum powder with fuel oil for lapping.

From the preceding discussion, you have learned that the air starting system may be the source of many troubles that will prevent an engine from cranking even though it can be barred over. You will avoid a few of these troubles by following prestarting and starting instructions. One such instruction, sometimes overlooked, is that of opening the valve in the air line. Obviously, with this valve closed the engine will not crank. Recheck the instructions for such oversights as a closed valve, an empty air storage receiver, or an engaged jacking gear before starting any disassembly.

ELECTRIC START MALFUNCTIONS

Electric starting system malfunctions fall into the following categories:

1. Nothing happens when the starter switch is closed.
2. Starter motor runs but does not engage the engine.
3. Starter motor engages but cannot turn the engine.

If nothing happens when you close the starter switch, there is a failure in the electrical system. The failure could be an open circuit caused by broken connections or burned out components. Test the circuit continuity to ensure that the relay closes and that the battery provides sufficient voltage and current to the starter circuit. If the circuit is complete, there may be resistance through faulty battery connections. Considerable current is needed to operate the solenoid and starter motor.

If the starter runs free of engagement, it will produce a distinctive hum or whine. The lack of engagement is usually caused by dirt or corrosion which prevents proper operation of the solenoid or Bendix gears.

If the starter motor engages the flywheel ring gear but is not able to turn the engine or cannot turn it quickly enough to obtain starting speed, the cause may be lack of battery power, or more likely, a mechanical problem. If the engine can be barred over, there is excessive friction in the meshing of the starter pinion and the ring gear. Either the teeth are burred, or the starter pinion is out of alignment. Either case would have been preceded by noise the last time the starter was used. A major repair may be necessary.

Other problems and malfunctions of electric starting systems are discussed in association with gasoline engines at the end of this chapter.

ENGINE CRANKS BUT FAILS TO START

Even when the starting equipment is in an operating condition, an engine may fail to start. A majority of the possible troubles which prevent an engine from starting are associated with fuel and the fuel system. However, defective or inoperative parts or assemblies may be the source of some trouble. Failure to follow instructions may be the cause of an engine failing to start. The corrective action is obvious for such items as leaving the fuel throttle in the OFF position and leaving the cylinder indicator valves open. If an engine fails to start, follow prescribed starting instructions and recheck the procedure.

Foreign Matter in the Fuel Oil System

In the operation of an internal-combustion engine, cleanliness is of paramount importance. This is especially true in the handling and care of diesel fuel oil. Impurities are the prime source of fuel pump and injection system troubles. Sediment and water cause wear, gumming, corrosion, and rust in a fuel system. Even though fuel oil is generally delivered clean from the refinery, handling and transferring increase the chances that fuel oil will become contaminated.

Corrosion often leads to replacement or at least to repair of the part. You must continually take steps to prevent water from accumulating in a fuel system, not only to eliminate the cause of corrosion but also to ensure proper combustion in the cylinders. Centrifuge all fuel, and drain the fuel filter cases periodically to prevent excessive collection of water.

Water in fuel will cause irreparable damage to the entire fuel system in a short time. It corrodes the fuel injection pump, where close clearances must be maintained, and also corrodes and erodes the injection nozzles. The slightest corrosion can cause a fuel injection pump to bind and seize which, if not corrected, will lead to excessive leakage. Water will erode the orifices of injection nozzles until they will not spray the fuel properly, thus preventing proper atomization. When this occurs, incomplete combustion and engine knocks result.

Air in the fuel system is another possible trouble which may prevent an engine from starting. Even if the engine will start, air in the fuel system will cause the engine to miss and knock, and perhaps to stall.

When an engine fails to operate, stalls, misfires, or knocks, there may be air in the high-pressure pumps and lines. In many systems, the expansion and compression of such air may take place even if the injection valves do not open. If this occurs, the pump is AIRBOUND. To determine if there is air in a fuel system, bleed a small amount of fuel from the top of the fuel filter; if the fuel appears quite cloudy, there are probably small bubbles of air in the fuel. Refer to chapter 10 of this manual for procedures in bleeding air from the fuel system.

Insufficient Fuel Supply

An insufficient fuel supply may result from any one of a number of defective or inoperative parts in the system. Such items as a closed inlet valve in the fuel piping or an empty supply tank are more likely to be the fault of the operator than of the equipment. But an empty tank may be caused by leakage, either in the lines or in the tank.

LEAKAGE.–You can usually trace leakage in the low-pressure lines of a fuel system to cracks in the piping; usually these cracks occur on threaded pipe joints at the root of the threads. Such breakage is caused by the inability of the nipples and pipe joints to withstand shock, vibration, and strains resulting from the relative motion between smaller pipes and the equipment to which they are attached.

Metal fatigue can also cause breakage. Each system should have a systematic inspection of the installation of fittings and piping to determine if all the parts are satisfactorily supported and sufficiently strong. In some instances, nipples may be connected to relatively heavy parts, such as valves and strainers, which are free to vibrate. Since vibration contributes materially to the fatigue of nipples, rigid bracing should be installed. When practicable, bracing should be secured to the unit itself, instead of to the hull or other equipment.

Breakage can also cause leakage in the high-pressure lines of a fuel system. The breakage usually occurs on either of the two end fittings of a line and is caused by lack of proper supports or by excessive nozzle opening pressure. Supports are usually supplied with an engine and should not be discarded. Excessive opening pressure of a nozzle–generally due to improper spring adjustment or to clogged nozzle orifices–may rupture the high-pressure fuel lines. A faulty nozzle usually requires removal, inspection, and repair plus the use of a nozzle tester.

Leakage from fuel lines may also be caused by improper replacement or repairs. When a replacement is necessary, always use a line of the same length and diameter as the one removed. Varying the length and diameter of a high-pressure fuel line will change the injection characteristics of the injection nozzle.

In an emergency, high-pressure fuel lines can usually be satisfactorily repaired by silver soldering a new fitting to the line. After making a silver solder repair, test the line for leaks and be certain no restrictions exist.

Most leakage trouble occurs in the fuel lines, but leaks may occasionally develop in the fuel tank. These leaks must be eliminated immediately because of potential fire hazard.

The principal causes of fuel tank leakage are improper welds and metal fatigue. Metal fatigue is usually the result of inadequate support at the source of trouble; excessive stresses develop in the tank and cause cracks.

CLOGGED FUEL FILTERS.–Another factor that can limit the fuel supply to such an extent that an engine will not start is clogged fuel filters. As soon as it is known that clogging exists, the filter elements should be replaced. Definite rules for such replacement cannot be established for all engines. Instructions generally state that elements will not be used longer than a specified time, and there are reasons that an element may not function properly even for the specified interval.

Filter elements may become clogged because of dirty fuel, too small filter capacity, failure to drain the filter sump, and failure to use the primary strainer. Usually, clogging is indicated by such symptoms as stoppage of fuel flow, increase in pressure drop across the filter, increase in pressure upstream of the filter, or excessive accumulation of dirt on the element (observed when the filter is removed for inspection). Symptoms of clogged filters vary in different installations, and each installation should be studied for external symptoms, such as abnormal instrument indications and engine operation. If external indications are not apparent, visual inspection of the element will be necessary, especially if it is known or suspected that dirty fuel is being used.

Fuel filter capacity should at least equal fuel supply pump capacity. A filter with a small capacity clogs more rapidly than a larger one, because the space available for dirt accumulation is more limited. There are two standardized sizes of fuel filter elements–large and small. The small element is the same diameter as the large but is only one-half as long. This construction permits substitution of two small elements for one large element.

You can increase the interval of time between element changes by using the drain cocks on a filter sump. Removal of dirt through the drain cock will make room for more dirt to collect.

If new filter elements are not available for replacement and the engine must be operated, you can wash some types of totally clogged elements and get limited additional service. This procedure is for emergencies only. An engine must never be operated unless all the fuel is filtered, therefore, a "washed filter" is better than none at all.

Fuel must never flow from the supply tanks to the nozzles without passing through all stages of filtration. Strainers, as the primary stage in the fuel filtration system, must be kept in good condition if sufficient fuel is to flow in the system. Most strainers have a blade mechanism which can be turned by hand. If you cannot readily turn the scraper by hand, disassemble and clean the strainer. This minor preventive maintenance will prevent the scraping mechanism from breaking.

TRANSFER PUMPS.–If the supply of fuel oil to the system is to be maintained in an even and uninterrupted flow, the fuel transfer pumps must be functioning properly. These pumps may become inoperative or defective to the point that they fail to discharge sufficient fuel for engine starting. Generally, when a pump fails to operate, some parts have to be replaced or reconditioned. For some types of pump, it is customary to replace the entire unit. However, for worn packing or seals, satisfactory repairs may be made. If plunger-type pumps fail to operate because the valves have become dirty, submerge and clean the pump in a bath of diesel oil.

Repairs of fuel transfer pumps should be made in accordance with maintenance manuals supplied by the individual pump manufacturers.

Malfunctioning of the Injection System

The fuel injection system is the most intricate of the systems in a diesel engine, and the troubles which may occur depend on the system in use. Since the function of an injection system is to deliver fuel to the cylinder at a high pressure, at the proper time, in the proper quantities, and properly atomized, special care and precautions must be taken in making adjustments and repairs.

HIGH-PRESSURE PUMP.–If a high-pressure pump in a fuel injection system becomes inoperative, an engine may fail to start. Information on the causes and remedies for an inoperative pump is more than can be given in the space available here. Information on injection systems is given in chapter 10 of this manual. Any ship using fuel injection equipment should have available copies of the applicable manufacturer's technical manual.

TIMING.–Regardless of the installation or the type of fuel injection system used, the timing of the injection system must be correct to obtain maximum energy from the fuel. Early or late injection timing may prevent an engine from starting. Operation will be uneven and vibration will be greater than usual.

If fuel enters a cylinder too early, detonation generally occurs, causing the gas pressure to rise too rapidly before the piston reaches top dead center. This in turn causes a loss of power and high combustion pressures. Low exhaust temperatures may be an indication that fuel injection is too early.

If fuel is injected too late in the engine cycle, overheating, lowered firing pressure, smoky exhaust, high exhaust temperatures, or loss of power may occur.

Follow the instructions in the manufacturer's technical manual to correct an improperly timed injection system.

Insufficient Compression

Proper compression pressures are essential if a diesel engine is to operate satisfactorily. Insufficient compression may cause an engine to fail to start. If low pressure is suspected as the reason, check the compression with the appropriate instrument. If the test indicates pressures below standard, disassembly is required for complete inspection and correction.

Inoperative Engine Governor

There are many troubles which may render a governor inoperative, but those encountered in starting an engine are generally caused by bound control linkage or, if the governor is hydraulic, by low oil level. Whether the governor is mechanical or hydraulic, binding of linkage is generally due to distorted, misaligned, defective, or dirty parts. If binding is suspected, move the linkage and governor parts and check by hand. Eliminate any undue stiffness or sluggishness in the movement of the linkage.

Low oil level in hydraulic governors may be caused by oil leaking from the governor or failure to maintain the proper oil level. Leakage of oil from a governor can generally be traced to a faulty oil seal on the drive shaft or power piston rod, or to a poor gasket seal between parts of the governor case.

Check the condition of the oil seals if oil must be added too frequently to governors with independent oil supplies. Depending on the point of leakage, oil seal leakage may or may not be visible on external surfaces. There will be no external sign if leakage occurs through the seal around the drive shaft, while leakage through the seal around the power piston will be visible.

Oil seals must be kept clean and pliable; therefore, the seals must be properly stored so that they do not become dry and brittle or dirty. The repair of leaky oil seals requires a replacement. You can prevent some of the leakage troubles by following proper installation and storage instructions for oil seals.

Most manufacturer's technical manuals supply information on the governor installed. Special hydraulic governor maintenance manuals made available by the Naval Sea Systems Command are:

Marquette Governor Manual, NavShips 341-5505.

Woodward Governor Manual, NavShips 341-5017.

Inoperative Overspeed Safety Devices

Overspeed safety devices are designed to shut off fuel or air in case of excessive engine speed. These devices must be maintained in operable condition at all times. Inoperative overspeed devices may cause an engine not to start. They may be inoperative because of improper adjustment, faulty linkage, a broken spring, or the overspeed device may have been accidentally tripped during the attempt to start the engine. The overspeed device must always be put in an operative condition before the engine is operated.

If the overspeed device fails to operate when the engine overspeeds, the engine may be secured by manually cutting off the fuel oil or the air supply to the engine. Most engines have special devices or valves to cut off the air or fuel in an emergency.

Insufficient Cranking Speed

If the engine cranks slowly, the necessary compression temperature cannot be reached. Low starting air pressure may be the source of such trouble.

Slow cranking speed may also be the result of an increase in the viscosity of the lubricating oil. This trouble occurs during periods when the air temperature is lower than usual. The oil specified for use during normal operation and temperature is not generally suitable for cold climate operation.

IRREGULAR ENGINE OPERATION

As the engine operator, you must constantly be alert to detect any symptoms which might indicate trouble. Forewarning is often given by sudden or abnormal changes in the supply, the temperature, or the pressure of the lubricating oil or the cooling water. Color and temperature of exhaust afford warning of abnormal conditions and you should check them frequently. Fuel, oil, and water leaks indicate possible troubles. Keep the engine clean to make such leaks easier to spot.

You will soon become accustomed to the "normal" sounds and vibrations of a properly operating engine. If you are alert, an abnormal or unexpected change in the pitch or tone of an engine's noise or a change in the magnitude or frequency of a vibration will warn you that all is not well. A new sound such as a knock, a drop in the fuel injection pressure, or a misfiring cylinder are other trouble warnings for which you should be constantly alert during engine operation.

The following discussion on possible troubles, their causes, and the corrective action necessary, is general rather than specific. The information is based on instructions for some of the engines used by the Navy and is typical of most. A few troubles listed may apply to only one model. For specific information on any particular engine, consult the manufacturer's technical manual.

ENGINE STALLS FREQUENTLY OR STOPS SUDDENLY

We discussed earlier several of the troubles which may cause an engine to stall or stop. Such troubles as air in the fuel system, clogged fuel filters, unsatisfactory operation of fuel injection equipment, and incorrect governor action not only cause starting failures or stalling but also may cause other troubles as well. For example, clogged fuel oil filters and strainers may lead to a loss of power, to misfires or erratic firing, or to low fuel oil pressure. Unfortunately, a single engine trouble does not always manifest itself as a single difficulty but may be the cause of several major difficulties.

Factors which may cause an engine to stall include misfiring, low cooling water temperature, improper application of load, improper timing, obstruction in the combustion space or in the exhaust system, insufficient intake air, piston seizure, and defective auxiliary drive mechanisms.

Misfiring

When an engine misfires or fires erratically or when one cylinder misfires regularly, the possible troubles are usually associated with the fuel or fuel system, worn parts, or the air cleaner or silencer. In determining what causes a cylinder to misfire, you should follow prescribed procedures in the appropriate technical manual. Procedures will vary among engines because of differences in the design of parts and equipment.

Many of the troubles caused by fuel contamination require overhaul and repair. However, a cylinder may misfire regularly in some systems because of the fuel pump cutout mechanism. Some fuel pumps have this type of mechanism so the fuel supply can be cut off from a cylinder to measure compression pressures. When a cylinder is misfiring, check first for an engaged cutout mechanism (if installed), and disengage it during normal engine operation.

LOSS OF COMPRESSION.–A cylinder may misfire due to loss of compression which may be caused by a leaking cylinder head gasket, leaking or sticking cylinder valves, worn pistons, liners or rings, or a cracked cylinder head or block. If loss of compression pressure causes an engine to misfire, check the compression pressure of each cylinder. Some indicators measure compression as well as firing pressure while the engine is running at full speed. Others check only the compression pressures with the engine running at a relatively slow speed. Figure 13-3 illustrates the application of some different types of pressure indicators.

After an indicator is installed, operate the engine at the specified rpm and record the cylinder compression pressure. Follow this procedure on each cylinder in turn. The pressure in any one cylinder should not be lower than the specified psi, nor should the pressure for any one cylinder be excessively lower than the pressures in the other cylinders. The maximum pressure variation permitted between cylinders is given on engine data sheets or in the manufacturer's technical manual. A compression leak is indicated when the pressure in one cylinder is considerably lower than that in the other cylinders.

A test indicating a compression leak means some disassembly, inspection, and repair. Check the valve seats and cylinder head gaskets for

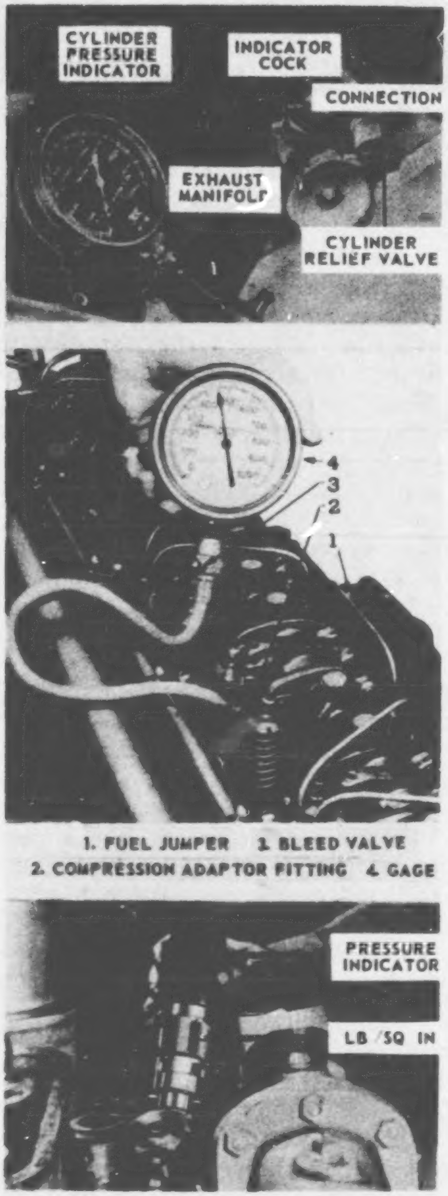

CYLINDER PRESSURE INDICATOR
INDICATOR COCK
CONNECTION
EXHAUST MANIFOLD
CYLINDER RELIEF VALVE
4
3
2
1
1. FUEL JUMPER 3. BLEED VALVE
2. COMPRESSION ADAPTOR FITTING 4. GAGE
PRESSURE INDICATOR
LB/SQ IN

Figure 13-3.–Engine cylinder pressure indicator applications. 75.238X

leaks, and inspect the valve stems for sticking. A cylinder head or block may be cracked. If these parts are not the source of trouble, compression is probably leaking past the piston because of insufficient sealing of the piston rings.

CLOGGED AIR CLEANERS AND SILENCERS.–Sometimes an engine will fire erratically or misfire because of clogged air cleaners and silencers. Air cleaners must be cleaned at specified intervals, as recommended in the engine manufacturer's technical manuals. A clogged cleaner reduces the intake air, thereby affecting the operation of the engine. Clogged air cleaners may cause not only misfiring or erratic firing but also such difficulties as hard starting, loss of power, engine smoke, and overheating.

When a volatile solvent is used for cleaning an air cleaner element, the element MUST be dry before it is reinstalled on the engine. Volatile solvents are excellent cleaning agents but, if permitted to remain in the filter, may cause engine overspeeding or a serious explosion.

Oil bath type air cleaners and filters cause very little trouble if serviced properly. Cleaning directions are usually given on the cleaner housing. The frequency of cleaning is usually based on a specified number of operating hours, but more frequent cleanings may be necessary where unfavorable conditions exist.

When filling an oil bath type cleaner, follow the manufacturer's instructions. Most air cleaners of this type have a FULL mark on the oil reservoir. Filling beyond this mark does not increase the efficiency of the unit and may lead to serious trouble. When the oil bath is too full, the intake air may draw oil into the cylinders. This excess oil-air mixture, over which there is no control, may cause an engine to "run away," resulting in serious damage.

Low Cooling Water Temperature

If an engine is to operate properly, the cooling water temperature must be maintained within specified temperature limits. When cooling water temperature drops lower than recommended for a diesel engine, ignition lag is increased, causing detonation, which results in "rough" operation and may cause an engine to stall.

The thermostatic valves that control cooling water temperature operate with a minimum of trouble. Cooling water temperatures above or below the value specified in the technical manual sometimes indicate an inoperative thermostat. However, high or low cooling water temperature does not always indicate thermostat trouble. The engine load may be insufficient to maintain proper cooling water temperatures, or the temperature gage may be inaccurate or inoperative. Check these items before removing a thermostatic control unit.

When a thermostat is suspected of faulty operation, it must be removed from the engine and tested.

A thermostat may be checked as follows:

1. A container which does not block or distort vision is needed. Fill the container with water.
2. Heat the water to the temperature at which the thermostat is supposed to start opening. This temperature is usually specified in the appropriate technical manual. Use an accurate thermometer to keep a check on the water temperature. Use a hot plate or a burner as a source of heat. Stir the water frequently to ensure uniform distribution of the heat.
3. Suspend the thermostat in such a manner that operation of the bellows will not be restricted. A wire or string will serve as a satisfactory means of suspension.
4. Immerse the thermostat and observe its action. Check the thermometer readings carefully to see whether the thermostat begins to open at the recommended temperature. (The thermostat and thermometer must NOT touch the container.)
5. Increase the temperature of the water until the specified FULL OPEN temperature is reached. The immersed thermostatic valve should be fully open at this temperature.

The thermostat should be replaced if there is no movement when it is tested, or if there is a divergence of more than a specified number of degrees between the temperature at which the thermostat begins to open, or opens fully, and the actuating temperatures specified in the manufacturer's technical manual.

The Fulton-Sylphon automatic temperature regulator is relatively trouble free. The unit controls temperatures by a valve that bypasses some water around the cooler. This system provides a full flow of the water although only a portion may be cooled. In other words, the full volume of cooling water is circulated at the proper velocity, which eliminates the possibility of steam pockets in the system.

Generally, improper adjustment is indicated when the automatic temperature regulator fails to maintain cooling water at the proper temperature. However, the element of the valve may be leaking or some part of the valve may be defective. Failure to follow the proper adjustment procedure is the only cause for improper adjustment of an automatic temperature regulator. Check and follow the proper procedure in the manufacturer's technical manual issued for the specific equipment.

The adjustment is made by changing the tension of the spring (which opposes the action of the thermostatic bellows) with a special tool that turns the adjusting stem knob or wheel. Increasing the spring tension raises the temperature range of the regulator, and decreasing it lowers the temperature range.

When a new valve of this type is placed in service, a number of steps must be taken to ensure that the valve stem is the proper length and that all scale pointers make accurate indications. All adjustments should be made in accordance with the valve manufacturer's technical manual.

Obstruction in the Combustion Space

Such items as broken valve heads and valve stem locks, or keepers, which come loose because of a broken valve spring, may cause an engine to come to an abrupt stop. If an engine continues to run when such obstructions are in the combustion chamber, the piston, liner, head, and injection nozzle will be severely damaged.

Obstruction in the Exhaust System

This type of trouble seldom occurs if proper installation and maintenance procedures are

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followed. When a part of an engine exhaust system is restricted, there will be an increase in the exhaust back pressure. This may cause high exhaust temperatures, loss of power, or even stalling. An obstruction which causes excessive back pressure in an exhaust system is generally associated with the silencer or muffler.

The manifolds of an exhaust system are relatively trouble free if related equipment is designed and installed properly. Improper design or installation may cause water to back up into the exhaust manifold. In some installations, the design of the silencer may cause water to flow into the engine. The source of water which may enter an engine must be found and eliminated. This may require replacing some parts of the exhaust system with components of an improved design or may require relocating such items as the silencer and piping.

Inspect exhaust manifolds for water or symptoms of water. Accumulation of salt or scale in the manifold usually indicates that water has been entering from the silencer. Turbochargers on some engines have been known to seize because saltwater entered the exhaust gas turbine from the silencer. Entry of water into an engine may also be detected by the presence of corrosion or of salt deposits on the engine exhaust valves.

If inspection reveals signs of water in an engine or in the exhaust manifold, take steps immediately to correct the trouble. Check the unit for proper installation. Wet-type silencers must be installed with the proper sizes of piping. If the inlet water piping is too large, too much water may be injected into the silencer. There must be continuous-type water drains on the silencer. If a silencer has no continuous drain and if the engine is at a lower level than the exhaust outlet, water may back up into the engine.

Dry-type silencers may become clogged with an excessive accumulation of oil or soot. When this occurs, exhaust back pressure increases, causing troubles such as high exhaust temperatures, loss of power, or possible stalling. A dry-type silencer clogged with oil or soot is also subject to fire. Clogging can usually be detected by fire, soot, or sparks coming from the exhaust stack. An excessive accumulation of oil or soot in a dry-type silencer may be due to a number of factors, such as failure to drain the silencer, poor condition of the engine, or improper engine operating conditions.

Silencers should be cleaned of oil and soot accumulations at necessary intervals. Even though recommended cleaning periods may be specified, conditions of operation may require more frequent inspections and cleaning. For example, an accumulation of soot and oil is more likely to occur during periods of prolonged idling than when the engine is operating under a normal load. Idling periods should be held to a minimum.

Insufficient Intake Air

Insufficient intake air, which may cause an engine to stall or stop, may be due to blower failure or to a clogged air silencer or air filter. Even though all other engine parts function perfectly, efficient engine operation is impossible if the air intake system fails to supply a sufficient quantity of air for complete combustion of the fuel.

Troubles that may prevent a centrifugal blower from performing its function usually involve damage to the rotor shaft, thrust bearings, turbine blading, nozzle ring, or blower impeller. Damage to the rotor shaft and thrust bearings usually results from insufficient lubrication, an unbalanced rotor, or operation with excessive exhaust temperature.

Centrifugal blower lubrication problems may be caused by failure of the oil pump to prime, low lube oil level, clogged oil passages or oil filter, or a defective relief valve which is designed to maintain proper lube oil pressure.

If an unbalanced rotor is the cause of shaft or bearing trouble, there will be excessive vibration. Unbalance may be caused by a damaged turbine wheel blading, or by a damaged blower impeller.

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Operating a blower when the exhaust temperature is above the specified maximum safe temperature generally causes severe damage to turbocharger bearings and other parts. Make every effort to find and eliminate causes of excessive exhaust temperature before the turbocharger is damaged.

Turbine blading damage in a centrifugal-type blower may be caused by operating with an excessive exhaust temperature, operating at excessive speeds, bearing failures, failure to drain the turbine casing, the entrance of foreign bodies or by turbine blades which break loose.

Damage to an impeller of a centrifugal blower may be caused by thrust or shaft bearing failure, entrance of foreign bodies, or loosening of the impeller on the shaft.

Since blowers are high-speed units and operate with a very small clearance between parts, minor damage to a part could cause extensive blower damage and failure.

Although there is considerable difference in principle and construction between the positive-displacement blower (Roots) and the axial-flow positive-displacement blower (Hamilton-Whitfield), the problems of operation and maintenance are similar.

Some of the troubles in a positive-displacement type blower are similar to those already mentioned in our discussion of the centrifugal-type blowers. However, the source of some troubles may be different because of construction differences.

Positive-displacement type blowers have a set of gears to drive and synchronize the rotation of the rotors. Many of these blowers are driven by a serrated shaft. Regardless of construction differences, the basic problem in both types of blowers is in maintaining the necessary small clearances. If these clearances are not maintained, the rotors and the case will be damaged, and the blower will fail to perform its function.

Worn gears are one source of trouble in positive-displacement type blowers. A certain amount of gear wear is expected, but damage caused by excessively worn gears indicates improper maintenance procedures. During inspections, the values of backlash should be recorded in accordance with PMS. This record can be used to establish the rate of increase in wear, to estimate the life of the gears, and to determine when it will be necessary to replace the gears.

Scored rotor lobes and casing may cause blower failure. Scoring of blower parts may be caused by worn gears, improper timing, bearing failure, improper end clearance, or by foreign matter. Any of these troubles may be serious enough to cause contact of the rotors and extensive damage to the blowers.

Timing of blower rotors involves both gear backlash and the clearances between the leading and trailing edges of the rotor lobes and between rotor lobes and casing. Clearance between these parts can be measured with thickness gages, as illustrated in figure 13-4. If clearances are incorrect, check the backlash of the drive gear first. If the backlash is excessive, the gears must be replaced. Then the rotors must be retimed according to the method outlined in the manufacturer's technical manual.

Failure of serrated blower shafts may be due to failure to inspect the parts or of improper replacement of parts. When inspecting serrated shafts, be sure that they fit snugly and that wear is not excessive. When serrations of either the shaft or hub have failed for any reason, both parts must be replaced.

Piston Seizure

Piston seizure may cause an engine to stop suddenly. The piston becomes galled and scuffed. When this occurs, the piston may possibly break or extensive damage may be done to other major engine parts. The principal causes of piston seizure are insufficient clearance, excessive temperatures, or inadequate lubrication.

Defective Auxiliary Drive Mechanisms

Defects in auxiliary drive mechanisms may cause an engine to stop suddenly. Since most

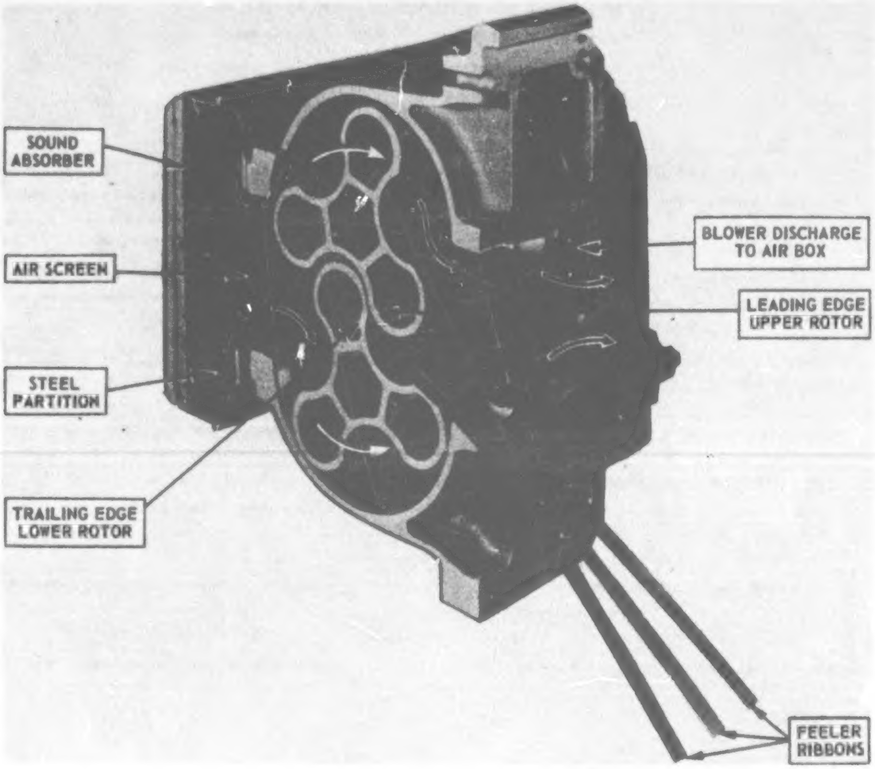

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Figure 13-4.–Checking clearances of positive-displacement blower lobes.

troubles in gear trains or chain drives require some disassembly, we shall limit our discussion to only the causes of such troubles.

Gear failure is the principal trouble in gear trains. Engine failure and extensive damage can occur because of a broken or chipped gear. If you hear a metallic clicking noise in the vicinity of a gear housing, it is almost a certain indication that a gear tooth has broken.

Gears are most likely to fail because of improper lubrication, corrosion, misalignment, torsional vibration, excessive backlash, wiped bearings and bushings, metal obstructions, or improper manufacturing procedures.

Gear shafts, bushings and bearings, and gear teeth must be checked during periodic inspections for scoring, wear, and pitting. All oil passages, jets, and sprays should be cleaned to ensure proper oil flow. All gear-locking devices must fit tightly to prevent longitudinal gear movement.

Chains are used in some engines for camshaft and auxiliary drives; in other engines, chains are used to drive certain auxiliary rotating parts. Troubles in chain drives are usually caused by wear or breakage. Troubles of this nature may be caused by improper tension, lack of lubrication, sheared cotter pins, or misalignment.

Figure 13-5 is a summary of the possible troubles which may cause an engine to stall frequently or stop suddenly. There may be some

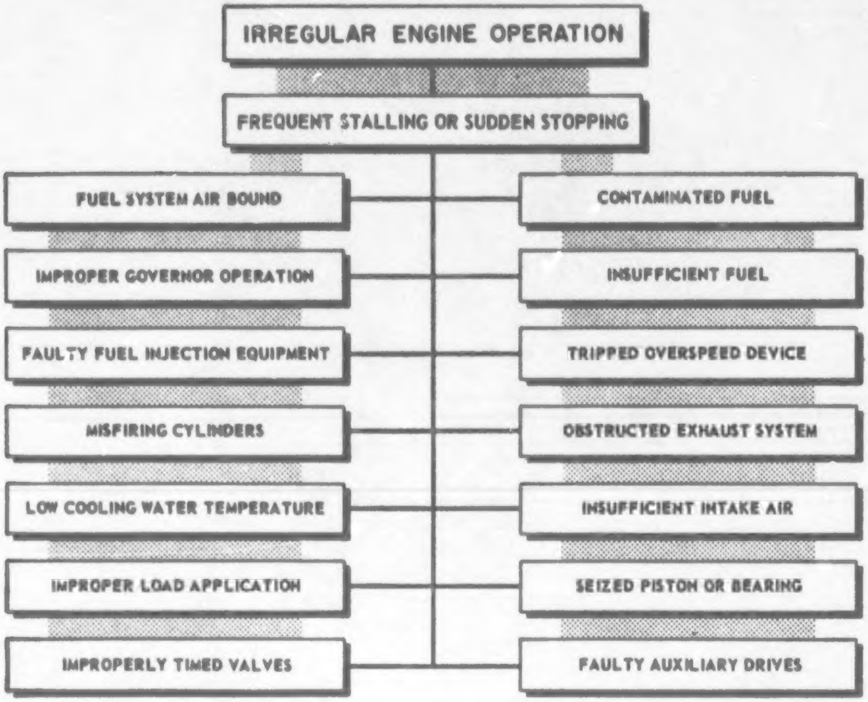
IRREGULAR ENGINE OPERATION
FREQUENT STALLING OR SUDDEN STOPPING
FUEL SYSTEM AIR BOUND
CONTAMINATED FUEL
IMPROPER GOVERNOR OPERATION
INSUFFICIENT FUEL
FAULTY FUEL INJECTION EQUIPMENT
TRIPPED OVERSPEED DEVICE
MISFIRING CYLINDERS
OBSTRUCTED EXHAUST SYSTEM
LOW COOLING WATER TEMPERATURE
INSUFFICIENT INTAKE AIR
IMPROPER LOAD APPLICATION
SEIZED PISTON OR BEARING
IMPROPERLY TIMED VALVES
FAULTY AUXILIARY DRIVES

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Figure 13-5.—Possible troubles which may cause an engine to stall frequently or to stop suddenly.

doubt as to the difference between stalling and stopping. In reality, there is none unless we associate certain troubles with each. In general, troubles which cause FREQUENT STALLING are those that can be eliminated with minor adjustments or maintenance. If such troubles are not eliminated, it is quite possible that the engine can be started, only to stall again. Failure to eliminate some of the troubles that cause frequent stalling may lead to troubles that cause SUDDEN STOPPING.

ENGINE WILL NOT CARRY LOAD

Many of the troubles that can lead to loss of power in an engine may also cause the engine to stop and stall suddenly or may even prevent it from starting. Compare the list of some of the troubles that may cause a power loss in the engine in figure 13-6 with those in figures 13-1 and 13-5. Such items as insufficient air, insufficient fuel, and faulty operation of the governor appear on all three charts. Many of the troubles listed are closely related, and the elimination of one may eliminate others.

The operator of an internal-combustion engine may be confronted with additional major difficulties, such as those indicated in figure 13-7. Here, again, you can see that many of these possible troubles are similar to those we have already discussed in connection with starting failures and with engine stalling and stopping. The discussion which follows covers only those troubles not previously considered.

ENGINE OVERSPEEDS

When an engine overspeeds, the trouble can usually be associated with either the governor mechanism or the fuel control linkage, as previously discussed. When information on a

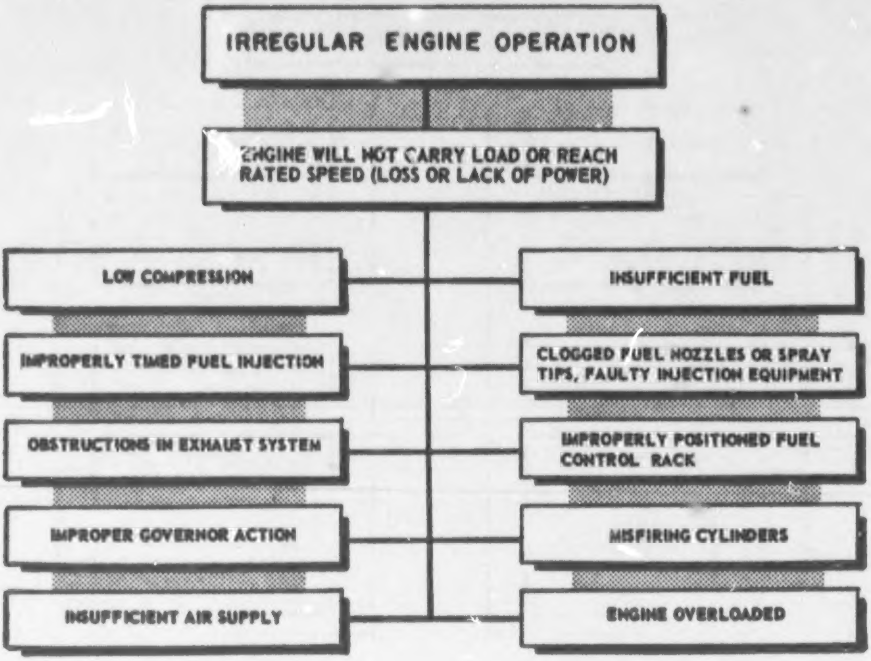
IRREGULAR ENGINE OPERATION
ENGINE WILL NOT CARRY LOAD OR REACH RATED SPEED (LOSS OR LACK OF POWER)
LOW COMPRESSION
IMPROPERLY TIMED FUEL INJECTION
OBSTRUCTIONS IN EXHAUST SYSTEM
IMPROPER GOVERNOR ACTION
INSUFFICIENT AIR SUPPLY
INSUFFICIENT FUEL
CLOGGED FUEL NOZZLES OR SPRAY TIPS, FAULTY INJECTION EQUIPMENT
IMPROPERLY POSITIONED FUEL CONTROL RACK
MISFIRING CYLINDERS
ENGINE OVERLOADED

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Figure 13-6.—Possible causes of insufficient power in an engine.

specific fuel system or speed control system is required, check the manufacturer's technical manual and the special technical manuals for the particular equipment. These special manuals are available for the most widely used models of hydraulic governors and overspeed trips, and they contain specific details on testing, adjusting, and repairing.

ENGINE HUNTS OR WILL NOT SECURE

Some troubles that may cause an engine to hunt are similar to those that may cause an engine to resist securing efforts. Generally, these two forms of irregular engine operation are caused by troubles originating in the fuel system and speed control system.

Speed Control System

The speed control system of an internal-combustion engine includes those parts designed to maintain the engine speed at some exact value or between desired limits, regardless of changes in load on the engine. Governors are provided to regulate fuel injection so that the speed of the engine can be controlled as the load is applied. Governors also prevent overspeeding as in rough seas when the load might be suddenly reduced when the propellers leave the water.

If certain parts of the fuel system or governor fail to function properly, the engine may hunt—that is, vary at a constant throttle setting—or it may be difficult to stop the engine.

Fuel Control Racks

Fuel control racks that have become sticky or jammed may cause governing difficulties. If the control rack of a fuel system is not functioning properly, the engine speed may increase as the load is removed or the engine may hunt continuously, or it may hunt only

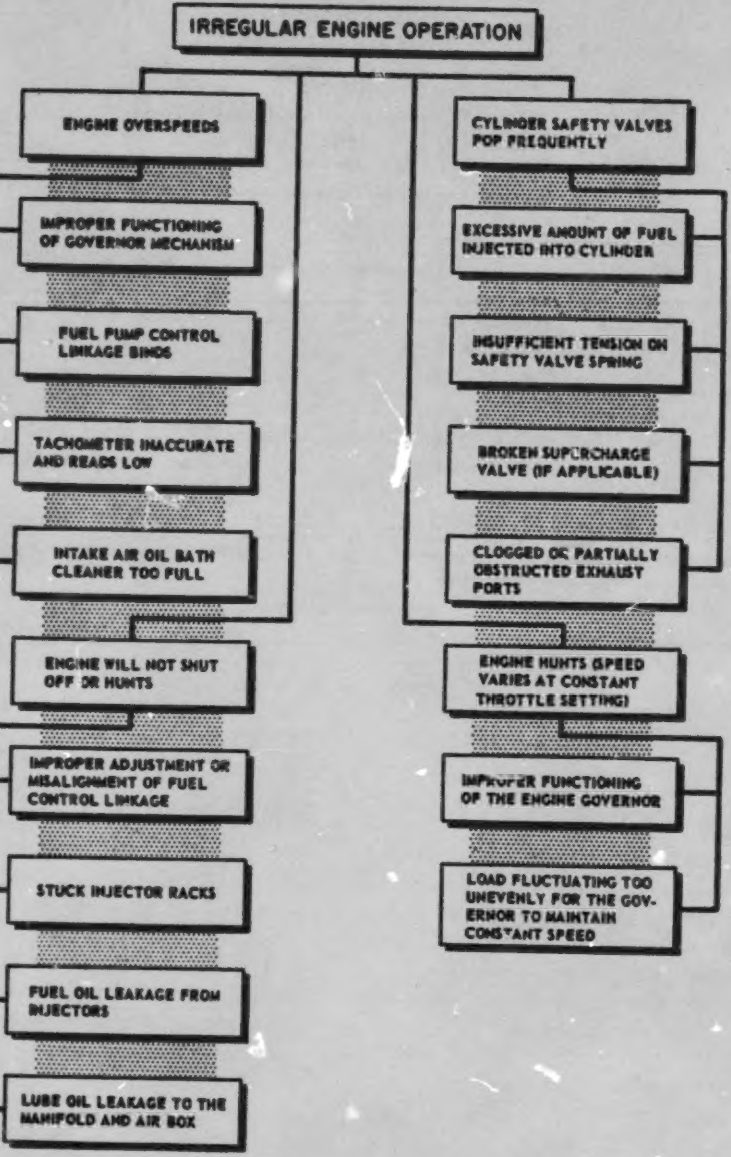
IRREGULAR ENGINE OPERATION
ENGINE OVERSPEEDS
IMPROPER FUNCTIONING OF GOVERNOR MECHANISM
FUEL PUMP CONTROL LINKAGE BINDS
TACHOMETER INACCURATE AND READS LOW
INTAKE AIR OIL BATH CLEANER TOO FULL
ENGINE WILL NOT SHUT OFF OR HUNTS
IMPROPER ADJUSTMENT OR MISALIGNMENT OF FUEL CONTROL LINKAGE
STUCK INJECTOR RACKS
FUEL OIL LEAKAGE FROM INJECTORS
LUBE OIL LEAKAGE TO THE MANIFOLD AND AIR BOX
CYLINDER SAFETY VALVES POP FREQUENTLY
EXCESSIVE AMOUNT OF FUEL INJECTED INTO CYLINDER
INSUFFICIENT TENSION ON SAFETY VALVE SPRING
BROKEN SUPERCHARGE VALVE (IF APPLICABLE)
CLOGGED OR PARTIALLY OBSTRUCTED EXHAUST PORTS
ENGINE HUNTS (SPEED VARIES AT CONSTANT THROTTLE SETTING)
IMPROPER FUNCTIONING OF THE ENGINE GOVERNOR
LOAD FLUCTUATING TOO UNEVENLY FOR THE GOVERNOR TO MAINTAIN CONSTANT SPEED

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Figure 13-7.—Additional causes of irregular engine operation.

when the load is changed. A sticky or jammed control rack may prevent an engine from responding to changes in throttle setting and may even prevent securing. Any such condition could be serious in an emergency situation. Your job is to make every effort possible to prevent such conditions from occurring.

You can check for a sticky rack by securing the engine, disconnecting the linkage to the governor, and then attempting to move the rack by hand. There should be no apparent resistance to the motion of the rack if the return springs and linkage are disconnected. A stuck control rack may be caused by the plunger's sticking in the pump barrel; dirt in the rack mechanism; damage to the rack, sleeve, or gear; or improper assembly of the injector pump.

The cause of sticking or jamming must be determined and damaged parts must be replaced. If sticking is due to dirt, a thorough cleaning of all parts will probably correct the trouble. Errors in assembly can be avoided by carefully studying the assembly drawings and instructions.

Leakage of Fuel Oil

Leakage of fuel oil from the injectors may cause an engine to continue to operate when you attempt to shut it down. Regardless of the type of fuel system, the results of internal leakage from injection equipment are, in general, somewhat the same. Injector leakage will cause unsatisfactory engine operation because of the excessive amount of fuel entering the cylinder. Leakage may also cause detonation, crankcase dilution, smoky exhaust, loss of power, and excessive carbon formation on spray tips of nozzles and other surfaces of the combustion chamber.

Accumulation of Lube Oil

Another trouble which may prevent you from stopping an engine is accumulation of lube oil in the intake air passages–manifold or air box. Such an accumulation creates an extremely dangerous condition. You can detect excess oil by removing inspection plates on covers and examining the air box and manifold. If oil is discovered, remove it and perform the necessary corrective maintenance. If oil is drawn suddenly in large quantities from the manifold or air box into the cylinder of the engine and burns, the engine may run away. The engine governor has no control over the sudden increase of speed that occurs.

An air box or air manifold explosion is also a possibility if excess oil is allowed to accumulate. Some engine manufacturers have provided safety devices to reduce the hazards of such explosions.

Excess oil in the air box or manifold of an engine also increases the tendency toward carbon formation on liner ports, cylinder valves, and other parts of the combustion chamber.

The causes of excessive lube oil accumulation in the air box or manifold will vary depending on the specific engine. Generally, the accumulation is due to an obstruction in either the air box or separator drains.

In an effort to reduce the possibility of crankcase explosions and runaways, some engine manufacturers have designed a means to ventilate the crankcase. In some engines, a passage between the crankcase and the intake side of the blower provides ventilation. In other engines, an oil separator or air maze in the passage between the crankcase and blower intake provides ventilation.

In either type of installation, stopped up drains will cause an excessive accumulation of oil. Drain passages must be kept open by proper cleaning whenever necessary.

Oil may enter the air box or manifold from sources other than crankcase vapors. A defective blower oil seal, a carryover from an oil type air cleaner, or defective oil piping may be the source of trouble.

Another possible source may be an excessively high oil level in the crankcase. Under this condition, an oil fog is created in some engines by the moving parts. An oil fog may also be caused by excessive clearance in the connecting rod and main journal bearings. In some types of crankcase ventilating systems, the oil fog will be drawn into the blower. When this occurs, an abnormal amount of oil may accumulate in the air box. Removal of the oil will not remove the trouble. The cause of the accumulation must be determined and the necessary repair must be accomplished.

If a blower oil seal is defective, replacement is the only satisfactory method of correction. When installing new seals, be sure the shafts are not scored and the bearings are in satisfactory condition. Special precautions must be taken during installation to avoid damaging oil seals. Damage to an oil seal during installation is usually not discovered until the blower has been reinstalled and the engine has been put into operation. Be sure an oil seal gets the necessary lubrication. The oil not only lubricates the seal, reducing friction, but also carries away any heat that is generated. New oil seals are generally soaked in clean, light lube oil before assembly.

CYLINDER SAFETY VALVES

On some engines, a cylinder relief (safety valve) is provided for each cylinder. The valve opens when the cylinder pressures exceed a safe operating limit. The valve opens or closes a passage leading from the combustion chamber to the outside of the cylinder. The valve face is held against the valve seat by spring pressure. Tension on the spring is varied by an adjusting nut, which is locked when the desired setting is attained. The desired setting varies with the type of engine and may be found by referring to the manufacturer's technical manual.

Cylinder relief valves should be set at the specified lifting pressure. Continual lifting (popping) of the valves indicates excessive cylinder pressure or malfunction of the valves, either of which should be corrected immediately. Repeated lifting of a relief valve indicates that the engine is being overloaded, the load is being applied improperly, or the engine is too cold. Also, repeated lifting may indicate that the valve spring has become weakened, ignition or fuel injection is occurring too early, the injector is sticking and leaking, too much fuel is being supplied, or, in air injection engines, that the spray valve air pressure is too high. When frequent popping occurs, the engine must be stopped to determine and remedy the cause of the trouble. In an emergency, the fuel supply may be cut off in the affected cylinder. Relief valves must NEVER be locked closed, except in an emergency. When emergency measures are taken, the valves must be repaired or replaced as necessary as soon as possible.

When excessive fuel is the cause of frequent safety valve lifting, the trouble may be due to the improper functioning of a high-pressure injection pump, a leaky nozzle or spray valve, or a loose fuel cam (if adjustable); or, in some systems such as the common rail, the fuel pressure may be too high.

A safety valve that is not operating properly should be removed, disassembled, cleaned and inspected. Check the valve and valve seat for pitting and excessive wear and the valve spring for possible defective conditions. When a safety valve is removed for any reason, the spring tension must be reset. This procedure varies to some extent, depending on the valve construction.

Except in emergencies, it is advisable to shut an engine down when troubles cause safety valve popping.

Clogged or partially obstructed exhaust ports may also cause the cylinder safety valve to lift. This condition will not occur often if proper planned maintenance procedures are followed. If it does occur, the resulting increase in cylinder pressure may be enough to cause safety valve popping. Clogged exhaust ports will also cause overheating of the engine, high exhaust temperatures, and sluggish engine operation.

You can prevent clogged cylinder ports by removing carbon deposits at prescribed intervals. Some engine manufacturers make special tools for port cleaning. Round wire brushes of the proper size are satisfactory for this work. You must be careful in cleaning cylinder ports to prevent carbon from entering the cylinder—bar the engine to such a position that the piston blocks the port.

SYMPTOMS OF ENGINE TROUBLE

In learning to recognize the symptoms that may help locate the causes of engine trouble, you will find that experience is the best teacher. Even though written instructions are essential for efficient troubleshooting, the information usually given serves only as a guide. It is very difficult to describe the sensation that you should feel when checking the temperature of a bearing by hand; the specific color of exhaust smoke when pistons and rings are worn excessively; and, for some engines, the sound that you will hear if the crankshaft counterweights come loose. You must actually work with the equipment in order to associate a particular symptom with a particular trouble. Written information, however, can save you a great deal of time and eliminate much unnecessary work. Written instructions will make detection of troubles much easier in practical situations.

Symptoms which indicate that a trouble exists may be in the form of an unusual noise or instrument indication, smoke, or excessive consumption or contamination of the lube oil, fuel, or water. Figure 13-8 is a general listing of various trouble symptoms which the operator of an engine may encounter.

NOISES

The unusual noises which may indicate that a trouble exists or is impending may be classified as pounding, knocking, clicking, and rattling. Each type of noise must be associated with certain engine parts or systems which might be the source of trouble.

Pounding or hammering is a mechanical knock (not to be confused with a fuel knock). It may be caused by a loose, excessively worn, or broken engine part. Generally, troubles of this nature will require major repairs.

Detonation (knocking) is caused by the presence of fuel or lubricating oil in the air charge of the cylinders during the compression stroke. Excessive pressures accompany detonation. If detonation is occurring in one or more cylinders, an engine should be stopped immediately to prevent possible damage.

Clicking noises are generally associated with an improperly functioning valve mechanism or timing gear. If the cylinder or valve mechanism is the source of metallic clicking, the trouble may be due to a loose valve stem and guide, insufficient or excessive valve tappet clearances, a loose cam follower or guide, broken valve springs, or a valve that is stuck open. A clicking in the timing gear usually indicates that there are some damaged or broken gear teeth.

NOISES	INSTRUMENT INDICATIONS			SMOKE	CONTAMINATION OF LUBE OIL, FUEL, OR WATER
	PRESSURE	TEMPERATURE	SPEED		
POUNDING (MECHANICAL)	LOW LUBE OIL PRESSURE	LOW LUBE OIL TEMPERATURE	IDLING SPEED NOT NORMAL	BLACK EXHAUST SMOKE	FUEL OIL IN THE LUBE OIL
	HIGH LUBE OIL PRESSURE	HIGH LUBE OIL TEMPERATURE	MAXIMUM SPEED NOT NORMAL	BLUISH-WHITE EXHAUST SMOKE	WATER IN THE LUBE OIL
KNOCKING (DETONATION)	LOW FUEL OIL PRESSURE (IN LOW-PRESSURE FUEL SUPPLY SYSTEM)	LOW COOLING WATER TEMPERATURE (FRESH)		SMOKE ARISING FROM CRANKCASE	OIL OR GREASE IN THE WATER
CLICKING (METALLIC)	LOW COOLING WATER PRESSURE (FRESH)	HIGH COOLING WATER TEMPERATURE (FRESH)		SMOKE ARISING FROM CYLINDER HEAD	WATER IN THE FUEL OIL
	LOW COOLING WATER PRESCURE (SALT)	LOW CYLINDER EXHAUST TEMPERATURE		SMOKE FROM ENGINE AUXILIARY EQUIPMENT (BLOWERS, PUMPS, ETC.)	AIR OR GAS IN THE WATER
RATTLING	HIGH COOLING WATER PRESSURE (SALT)	HIGH EXHAUST TEMPERATURE IN ONE CYLINDER			METAL PARTICLES IN LUBE OIL
	LOW COMPRESSION PRESSURE				
	LOW FIRING PRESSURE				
	HIGH FIRING PRESSURE				
	LOW SCAVENGING AIR RECEIVER PRESSURE (SUPERCHARGE ENGINE)				
	HIGH EXHAUST BACK PRESSURE				

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Figure 13-8.—Symptoms of engine trouble.

Rattling noises are generally due to vibration of loose engine parts. However, an improperly functioning vibration damper, a failed antifriction bearing, or a gear-type pump operating without prime are also possible sources of trouble when rattling noises occur.

When you hear a noise, first make sure that it is a trouble symptom. Each diesel engine has a characteristic noise at any specific speed and load. The noise will change with a change in speed or load. As an operator you must become familiar with the normal sounds of an engine. Abnormal sounds must be investigated promptly. Knocks which indicate a trouble may be detected and located by special instruments or by the use of a "sounding bar" such as a solid iron screwdriver or bar.

INSTRUMENT INDICATIONS

An engine operator probably relies more on the instruments to warn of impending troubles than on all the other trouble symptoms combined. Regardless of the type instrument being used, the indications are of no value if inaccuracies exist. Be sure an instrument is accurate and operating properly. All instruments must be tested at specified intervals or whenever they are suspected of being inaccurate.

SMOKE

Smoke can be quite useful as an aid in locating some types of trouble, especially if used in conjunction with other trouble symptoms. The color of exhaust smoke can also be used as a guide in troubleshooting.

The color of engine exhaust is a good, general indication of engine performance. The exhaust of an efficiently operating engine has little or no color. A dark, smoky exhaust indicates incomplete combustion; the darker the color, the greater the amount of unburned fuel in the exhaust. Incomplete combustion may be due to a number of troubles. Some manufacturers associate a particular type of trouble with the color of the exhaust. The more serious troubles are generally identified with either black or bluish-white exhaust colors.

EXCESSIVE CONSUMPTION OF LUBE OIL, FUEL, OR WATER

An operator should be aware of engine trouble whenever excessive consumption of any of the essential liquids occurs. The possible troubles indicated by excessive consumption will depend on the system in question; leakage, however, is one trouble which may be common to all. Before starting any disassembly, check for leaks in the system in which excessive consumption occurs.

TROUBLESHOOTING GASOLINE ENGINES

The troubleshooting procedures used for a marine gasoline engine are, in many ways, similar to those for a diesel engine. The main parts and systems of the two types of engines are quite similar with two exceptions. They differ principally in the manner of getting fuel and air into the cylinders and in the method of ignition.

This section deals primarily with those systems which differ in the gasoline and diesel engines. In, addition, troubleshooting information is given on the electrical systems.

Even though most electrical maintenance and repair is the responsibility of an Electrician's Mate, you as an Engineman can reduce the amount of electrical troubles by following the correct operating procedures. Most electrical system troubles develop from improper use, care, or maintenance.

The following information is given primarily to help you in detecting electrical troubles so that corrective action may be taken.

When a gasoline engine fails to start, one of three conditions exists. The engine is not free to turn, the starter does not crank the engine, or the engine is cranked but does not start. Figure 13-9 lists many of the parts and conditions which may be the source of trouble causing such difficulties.

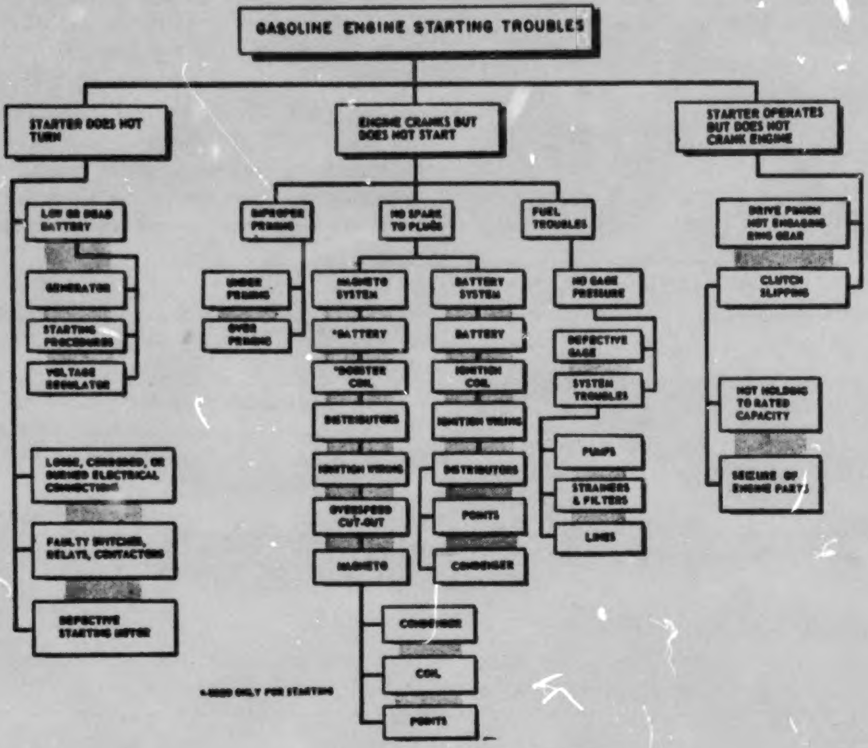
GASOLINE ENGINE STARTING TROUBLES
STARTER DOES NOT TURN
ENGINE CRANKS BUT DOES NOT START
STARTER OPERATES BUT DOES NOT CRANK ENGINE
LOW OR DEAD BATTERY
GENERATOR
STARTING PROCEDURES
VOLTAGE REGULATOR
LOOSE, CORRODED, OR BURNED ELECTRICAL CONNECTIONS
FAULTY SWITCHES, RELAYS, CONTACTORS
DEFECTIVE STARTING MOTOR
IMPROPER PRIMING
UNDER PRIMING
OVER PRIMING
NO SPARK TO PLUGS
MAGNETO SYSTEM
*BATTERY
*BOOSTER COIL
DISTRIBUTORS
IGNITION WIRING
OVERSPEED CUT-OUT
MAGNETO
CONDENSER
COIL
POINTS
BATTERY SYSTEM
BATTERY
IGNITION COIL
IGNITION WIRING
DISTRIBUTORS
POINTS
CONDENSER
FUEL TROUBLES
NO GAGE PRESSURE
DEFECTIVE GAGE
SYSTEM TROUBLES
PUMPS
STRAINERS & FILTERS
LINES
DRIVE PINION NOT ENGAGING RING GEAR
CLUTCH SLIPPING
NOT HOLDING TO RATED CAPACITY
SEIZURE OF ENGINE PARTS
*USED ONLY FOR STARTING

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Figure 13-9.—Possible sources of trouble when a gasoline engine fails to start.

If the engine will not turn over, some part is probably seized. In this event it is advisable to make a thorough inspection which may necessarily include some disassembly.

STARTER DOES NOT RUN

If the starter fails to turn, the trouble can usually be traced to the battery, connections, switch, or starter motor.

Symptoms of battery trouble generally occur before the charge gets too low to perform the required work. Battery failure is normally preceded by a gradual decline in the strength of the battery charge. A dead battery may be the result of insufficient charging, damaged plates, or improper starting technique.

Generators used to maintain the charge of starting batteries may become defective. When this occurs, the normal symptoms are a low battery charge when the engine is started and a zero or low ammeter reading when the engine is running.

Batteries must be in good condition to ensure the proper operation of an ignition system. A starter draws a heavy current from the best of batteries. When a battery is weak, the voltage will be insufficient to operate the ignition system satisfactorily because the heavy starting current will drop the voltage of the battery to an extremely low value.

Flames and sparks of all kinds should be kept away from the vicinity of storage batteries. A certain amount of hydrogen gas is given off from a battery at all times. In confined spaces this gas can form a dangerous explosive mixture.

When using tools around a battery, you should be careful not to short circuit the battery terminals. Never use a tool or metal object to make a so-called "test" of a storage battery.

Batteries in exposed locations subject to low temperatures should be kept fully charged during cold weather. In extreme cold weather, storage batteries should be removed and placed in a warm compartment, if it is practicable to do so.

Electrical connections are another possible source of trouble if the starter does not turn. All connections must be kept tight and free from corrosion if maximum capacity is to be obtained from the battery. Battery terminals, since they are more vulnerable to corrosion, looseness, and burning, are the principal sources of trouble.

Burned battery terminals may be caused by a loose connection, a corroded terminal, or a short circuit. Burning of terminals usually occurs when an engine is being started. Burning may be indicated by such things as smoke, a flash, or a spattering of molten metal in the vicinity of the battery. Usually, the starting motor will cease to turn after the occurrence of these symptoms.

Switches, electrical relays, or contactors which are defective or inoperative may be the reason that a starter will not turn. Contactors, being subject to extremely high current, must be maintained in the best possible condition. Starting contactors are either manually or magnetically operated and are designed to be operated for only short periods of time.

Starter motor troubles can be traced for the most part to the commutator, brushes, or insulation. If motors are to function properly, they must be kept clean and dry; dirt and moisture make good commutation impossible. Dirty and fouled starter motors may be caused by failure to replace the cover band, by water leakage, or by excess lubrication.

Most starter motors have a cover to protect the commutator and windings. If the operator neglects to replace the cover or removes it as an aid to ventilation and cooling, dirt and water are sure to damage the equipment.

Although lubrication of bearings is essential for proper operation, excessive lubrication may lead to trouble in a starter motor. Excess lubricant in the shaft bearings may leak or be forced past the seal and foul the insulating material, commutator, and brushes. The lubricant prevents a good electrical contact between the brushes and commutator, causing sparking and heating of the commutator and burning of the brushes.

Burned brushes are another possible source of trouble if the starter motor is inoperative. Burning may be caused by loose brush holders, improper brush spring tension, a brush stuck in the holder, a dirty commutator, improper brush seating surface, and overloading the starter.

STARTER MOTOR OPERATES BUT DOES NOT CRANK ENGINE

If the starter motor and battery are known to be in good operating condition but the starter fails to crank the engine, the trouble will usually be found in the drive connection between the motor and the ring gear on the flywheel. Troubles in the drive assembly are usually in the form of broken parts or a slipping clutch (if applicable). A slipping clutch may be the result of the engine not being free to turn or of the clutch not holding up to its rated capacity.

Even though seldom encountered, a stripped ring gear on the flywheel may be the source of trouble if the starter motor does not turn the engine.

ENGINE CRANKS BUT FAILS TO START

Starting troubles and their causes and corrections may vary to some degree, depending on the particular engine. If the prescribed prestarting and starting procedures are followed and a gasoline engine fails to start, the source of trouble will probably be improper priming or choking, a lack of fuel at various points in the system, or a lack of spark at the spark plugs.

Improper priming may be classified as either underpriming or overpriming. Priming instructions differ, depending on the engine. Information on priming also applies to engines equipped with chokes. A warm engine should never be primed. Some engines may require no priming except when starting under cold weather conditions.

On some installations, underpriming can be checked by the feel of the primer pump as it is operated. On other installations, underpriming may be due to insufficient use of the choke.

Overpriming results in a flooded engine and makes starting difficult. Overpriming is also undesirable because excess gasoline will condense in the intake manifolds, run down into the cylinders, wash away the lubricating oil film, and cause pistons or rings to stick.

Flooding can be determined by removing and inspecting a spark plug. A wet plug indicates flooding. Deflooding or drying out procedures must be accomplished according to prescribed instructions. Some installations specify that the ignition switch must be ON, while others state the switch must be OFF; therefore it is important that the appropriate engine manufacturer's instructions be followed.

Improper carburetion may be the source of trouble if a gasoline engine fails to start. On some engines a check of the fuel pressure gage will indicate whether lack of fuel is the cause. If the gage shows the prescribed pressure, the trouble is not lack of fuel; if the gage shows little or no fuel pressure, then the various parts of the delivery system must be checked to locate the fault.

In some installations, you can determine whether the trouble is in the gage or in the fuel system by the following procedure: (1) remove the carburetor plug next to the fuel pressure gage connection, and (2) use a suitable container to catch the gasoline and operate the pump used to build up starting fuel pressure. If fuel is reaching the carburetor, gasoline will spurt out of the open plug hole; this indicates that the gage is inoperative. If no fuel flows from the plug opening, the trouble is probably in the fuel system somewhere between the fuel tank and carburetor. Even though all installations do not have a fuel pressure gage, the procedure for checking the fuel system will be much the same.

If a wobble pump is installed to build up starting fuel pressure, you can determine whether the pump is operating correctly by the feel and sound of the pump. If the pump feels or sounds dry, then the trouble is between the pump and supply tanks. The trouble might be caused by a clogged fuel line strainer or by an air leak in the line. If the wobble pump is pumping, then the trouble may be in the line to the engine fuel pump or in the engine fuel pump itself.

Check the fuel lines for cracks, dents, loose connections, sharp bends, and clogging. You can remove the fuel line at the pump and use air to determine if the line is open.

Check fuel pumps for leaks at the pump gaskets or in the fuel line connections. Check fuel pump filters or sediment bowl screens for restrictions. Check the bypass for operation. If the bypass valve is defective, the fuel pump will have to be replaced. In diaphragm type fuel pumps, the filter bowl gasket, the diaphragm, or the valves may be the source of trouble. Check for air leaks by submerging the discharge end of the fuel line in gasoline and looking for air bubbles while cranking the engine. If the engine will run, a leaky diaphragm can be detected by gasoline leakage from the pump air vent.

Carburetor trouble may be the reason if fuel does not reach the cylinders. This can be checked by removing the spark plugs and looking for moisture. If there is no trace of gasoline on the plugs, the carburetor may be out of adjustment, the float level may be too low, or the jets may be clogged. If the fuel level in the carburetor float bowl is low, the float valve is probably stuck on the seat. If the fuel level in the float is correct, yet no fuel is delivered to the carburetor throat, the carburetor will have to be removed, disassembled, and cleaned.

Faulty ignition system parts may be the source of starting difficulties. You may encounter two kinds of ignition systems–the MAGNETO type and the BATTERY type. Even though the parts of these systems differ in some respects, their function is the same; namely, to produce a spark in each cylinder of the engine at exactly the proper time in relation to the position of the pistons and the crankshaft. Also, the system is so designed that the sparks in all cylinders follow each other in proper sequence.

ENGINE FAILS TO STOP

If a gasoline engine fails to stop when the ignition switch is turned to the OFF position, the trouble is usually caused by a faulty ignition circuit, improper timing, the octane rating number of the fuel is too low for the design of the engine, or the engine is overheated.

In a magneto type ignition system, an open ground connection may cause an engine to run after the ignition switch is turned off. When a magneto ground connection is open, the magneto will continue to produce sparks as long as the magneto armature magnets rotate, and the engine will continue to run. In other words, when the magneto ignition switch contact points are closed, the ignition should be SHUT OFF. This is not true of the booster coil circuit of a magneto type system, nor of the usual battery type ignition system. In these systems, an open ground or open switch points prevent current flow. If the switch of a battery type ignition system fails to stop an engine, it is probable that the contact switch points have remained closed.

If the ignition switch and the circuit are in good condition, failure to stop may be caused by overheating. If the engine is overheated, normal compression temperature may become high enough to ignite the fuel mixture even though no spark is being produced in the cylinders. When this happens in a gasoline engine, the engine is in reality operating on the diesel principle.

Normally, you will detect the symptoms of overheating before the temperature gets too high. The causes of overheating in a gasoline engine are much the same as those for a diesel engine.

Other troubles and their symptoms, causes, and corrections which may occur in a gasoline engine are similar to those found in a diesel engine. Troubles leading to loss of rpm, irregular operation, unusual noises, abnormal instrument indications, and excessive consumption or contamination of the lube oil, fuel, or water, can usually be handled in the same way for gasoline and diesel engines. Of course, there are always exceptions, so it is best to consult the appropriate manufacturer's technical manual.

ELECTRICAL SYSTEMS

Since most small boat crews do not include an electrician when away from the ship, it will be the responsibility of the engineer to troubleshoot and repair troubles that may be encountered with the electrical ignition and lighting systems. The ignition systems have been discussed earlier in this manual, so the information here will mostly apply to lighting systems.

The electrical system on a typical small boat consists of the following:

1. A battery charging generator driven from the propulsion engine.
2. An engine starting system.
3. A battery used both for engine starting and for supplying auxiliary loads when the engine is secured.
4. A control and distribution panel having switches and fuses for the control and protection of circuits to auxiliary loads.
5. Cable for interconnecting the above.
6. Voltage regulator.

UNGROUNDED TWO-WIRE, 24-VOLT D.C. SYSTEM

The electrical system used on Navy small boats is generally a two-wire, ungrounded, 24-volt d.c. system. The two-wire system is a necessity on a nonconducting boat hull of wood or plastic. The steel boat hull, like the automobile chassis, makes a good electrical conductor and permits the use of a single-wire electrical system with a grounded or hull return. There are certain reasons, however, for the use of an ungrounded two-wire system on steel hull boats instead of the single-wire installation.

Because of environmental conditions (exposure to saltwater spray), an unwanted (accidental) ground sometimes occurs on boat electrical systems. The Navy's service experiences reveal that fewer shutdowns occur on its ungrounded two-wire systems than on the single-wire systems. As a result, every effort is made to provide a two-wire ungrounded system and the Electrician's Mate must maintain it in that condition. The ungrounded systems can tolerate the temporary addition of any SINGLE grounded condition, regardless of its location, because no function is affected. A variety of troubles however may result when two places in the system become ungrounded. The more common troubles include blown fuses, failure to energize the starting system, or faulty operation of any device, such as horn, voltage regulator, lights, and miscellaneous auxiliary loads.

PROTECTION OF CIRCUITS

Fuses are normally provided only in the circuits supplying auxiliary loads such as horns, running lights, cabin lights, spotlights, and communications equipment.

All other circuits, such as the starting motor circuit, solenoid switch control circuit, battery charging circuit, and power supply to the distribution panel, are unfused. Protection of the unfused circuits is adequate because the possibility of short circuits or leakage currents has been reduced by providing the following:

1. Two-wire ungrounded electrical system instead of single-wire grounded.
2. Two-wire ungrounded electrical components of such rugged construction as to make grounding of internal wiring or terminals most difficult under normal service conditions.
3. Watertight components such as battery connection boxes, distribution and control panel, and starting motor solenoid switch.
4. Cables between batteries and starting motor of sufficient size to carry high inrush currents and provided with terminal lugs and end sealing to prevent penetration of moisture.
5. Splash guards for attached generators.
6. Protection of instruments such as the battery charging ammeter by providing sealed meters or a transparent splash shield.
7. Fusing of auxiliary load circuits to isolate faults in these circuits.

When working around an engine or boat it will be to your advantage to pay particular attention to how a unit is wired and the type of wiring used. It will make the job of finding and repairing troubles much easier.

Although on a small boat away from the ship, it will be rather difficult to completely check out a system since the test equipment will not be available.

However, you can check for such things as loose, or corroded connections, broken wiring, faulty switches, and blown bulbs or fuses.

More detailed information pertaining to a particular installation can be obtained from the manufacturer's technical manual.

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CHAPTER 14

TRANSMISSION OF ENGINE POWER

The main components of an engine have been covered in the preceding chapters of this manual. If the power developed by an engine is to be used to perform useful work, there must be some way to transmit the power from the engine (driving unit) to such loads as the propeller of a boat or the drive shaft of a generator, a compressor, or a pump. This chapter provides general information on how the force available at the crankshaft of an engine is transmitted to a point where it will perform useful work. The combination of devices used to transmit engine power to a driven unit is commonly called a DRIVE MECHANISM.

FACTORS RELATED TO THE TRANSMISSION OF ENGINE POWER

The basic characteristics of an internal-combustion engine make it necessary, in many cases, for the drive mechanism to change both the speed and the direction of shaft rotation in the driven mechanism. There are various methods for making required changes in speed and direction during the transmission of power from the driving unit to the driven unit. In most of the installations you will be working with, the power is transmitted by a drive mechanism consisting principally of gears and shafts. You will better understand the way a drive mechanism transmits power if you review chapters 1 through 9 of *Basic Machines*, NAVPERS 10624-A. Chapter 6 will be especially helpful to you; it describes the basic types of gears and discusses how gears are used to change the direction of rotation and the speed of a shaft.

The process of transmitting engine power to a point where it can be used in performing useful work involves a number of factors. Two of these factors are torque and speed.

TORQUE

Torque, or twist, is the force which tends to cause a rotational movement of an object. The crankshaft of an engine supplies a twisting force to the gears and shafts which transmit power to the driven unit. Gears are used to increase or decrease torque. For example, an engine may not produce enough torque to turn the shaft of a driven machine if the connection between the driving and driven units is direct, or "solid." If the right combination of gears is installed between the engine and the driven unit, however, torque is increased, and the twisting force is then sufficient to operate the driven unit.

SPEED

Another factor related to torque and to the transmission of engine power is engine speed. If maximum efficiency is to be obtained, an engine must operate at a certain speed. To obtain efficient engine operation, in some installations the engine may need to operate at a higher speed than that required for efficient operation of the driven unit. In other installations, the speed of the engine may need to be lower than the speed of the driven unit. Through a combination of gears, the speed of the driven unit can be increased or decreased so that both the driving and the driven units operate at their most efficient speeds; that is, so that the proper speed ratio exists between the units.

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Speed Ratio and Gear Ratio

The terms speed ratio and gear ratio are frequently used in descriptions of gear-type mechanisms. Both ratios are determined by dividing the number of teeth on the driven gear by the number of teeth on the driving gear. For example, assume that the crankshaft of a particular engine is fitted with a driving gear which is half as large as the meshing, driven gear. If the driving gear has 10 teeth and the driven gear has 20 teeth, the gear ratio is 2 to 1. Every revolution of the driving gear will cause the driven gear to revolve through only half a turn. Thus, if the engine is operating at 2,000 rpm, the speed of the driven gear will be only 1,000 rpm; the speed ratio is then 2 to 1. This arrangement doubles the torque on the shaft of the driven unit; the speed of the driven unit, however, is only half that of the engine.

On the other hand, if the driving gear has 20 teeth and the driven gear has 10 teeth, the speed ratio is 1 to 2, and the speed of the driven gear is doubled. The rule applies equally well when an odd number of teeth is involved. If the ratio of the teeth is 37 to 15, the speed ratio is slightly less than 2.47 to 1; in other words, the driving gear will turn through almost two and a half revolutions while the driven gear makes one revolution. The gear with the greater number of teeth, which will always revolve more slowly than the gear with the smaller number of teeth, will produce the greater torque. Gear trains which change speed always change torque; when speed increases, the torque decreases proportionally.

TYPES OF DRIVE MECHANISMS

You have just learned that the torque and the speed of an engine may need to be changed to satisfy the torque and speed requirements of the driven mechanism. The term indirect drive, as used in this chapter, describes a drive mechanism which changes speed and torque. Drives of this type are common to many marine engine installations.

When the speed and the torque of an engine do NOT need to be changed to drive a machine satisfactorily, the mechanism used is a DIRECT DRIVE. Drives of this type are commonly used when the engine furnishes power for the operation of auxiliaries, such as generators and pumps.

INDIRECT DRIVES

The drive mechanisms of most engine-powered ships and of many boats are the indirect type. With this drive, the power developed by the engine(s) is transmitted to the propeller(s) indirectly, through an intermediate mechanism which reduces the shaft speed. Speed may be reduced mechanically, by a combination of gears, or by electrical means.

Mechanical Drives

The mechanical drives discussed in this chapter include devices which reduce the shaft speed of the driven unit, provide a means for reversing the direction of shaft rotation in the driven unit, and permit quick-disconnect of the driving unit from the driven unit.

Propellers operate most efficiently in a relatively low rpm range. The most efficient designs of diesel engines, however, operate in a relatively high rpm range. In order that both the engine and propeller may operate efficiently, the drive mechanism in many installations includes a device which permits a speed reduction from engine shaft to propeller shaft. The combination of gears which brings about the speed reduction is called a REDUCTION GEAR. In most diesel engine installations, the reduction ratio does not exceed 3 to 1. There are some units, however, which have reductions as high as 6 to 1.

The propelling equipment of a boat or a ship must provide backing-down power as well as forward motion power. In a few ships and boats backing down is accomplished by reversing the pitch of the propeller; in most ships, however, backing down is accomplished by reversing the direction of rotation of the propeller shaft. In mechanical drives, the direction of rotation of the propeller shaft is reversed in one of two ways: by reversing the direction of engine rotation; or by using REVERSE GEARS. Of these two methods, reverse gears are more commonly used in modern installations.

The drive mechanism of a ship or boat must do more than reduce speed and change direction of rotation. Most drive mechanisms have a CLUTCH, which disconnects the drive mechanism from the propeller shaft and permits the engine to be operated without turning the propeller shaft.

The arrangement of the components in an indirect drive varies, depending upon the type and size of the installation. In some small installations the clutch, the reverse gear, and the reduction gear may be combined in a single unit. In other installations the clutch and the reverse gear may be in one housing with the reduction gear in a separate housing attached to the reverse-gear housing. Drive mechanisms arranged in either manner are usually called TRANSMISSIONS. The arrangement of the components in two different types of transmissions are shown in figures 14-1 and 14-2.

In the transmission shown in figure 14-1, the housing is divided into two sections by the bearing carrier. The clutch assembly is in the forward section, and the gear assembly is in the after section of the housing. In the transmission shown in figure 14-2, note that the clutch assembly and the reverse-gear assembly are in one housing, while the reduction-gear unit is in a separate housing (attached to the clutch and the reverse-gear housing).

In large engine installations, the clutch and the reverse gear may be combined; they may be separate units, located between the engine and a separate reduction gear; or the clutch may be separate and the reverse gear and the reduction gear may be combined.

In most geared-drive multiple propeller ships, the propulsion units and their drive mechanisms are independent of each other. In others, the drive mechanism is arranged so that two or more engines can drive a single propeller. In one newer type of installation, the CODOG (combination diesel or gas) system, each propeller is driven by a diesel engine or both propellers are driven by one gas turbine (fig. 14-3). The diesel engines are used for normal

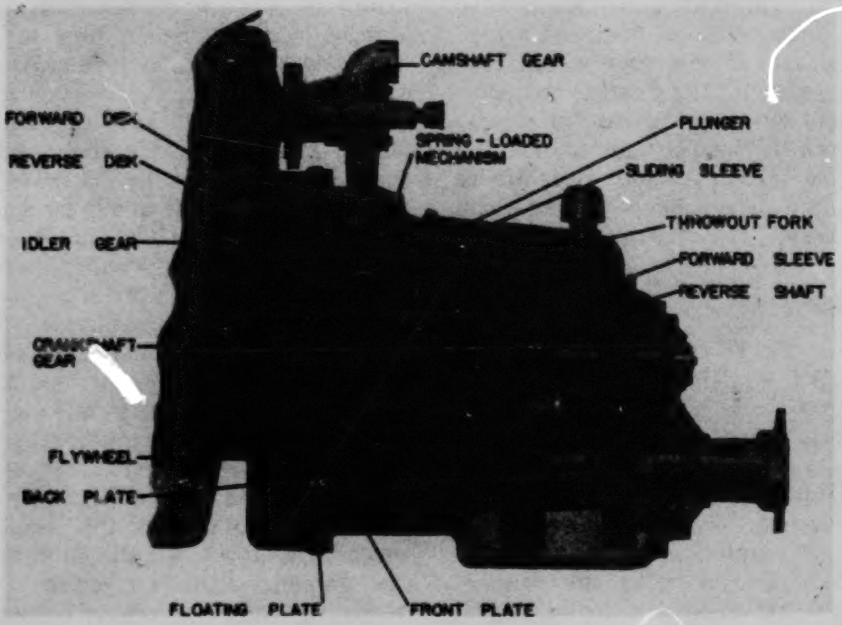

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Figure 14-1.—Transmission with independent oil systems.

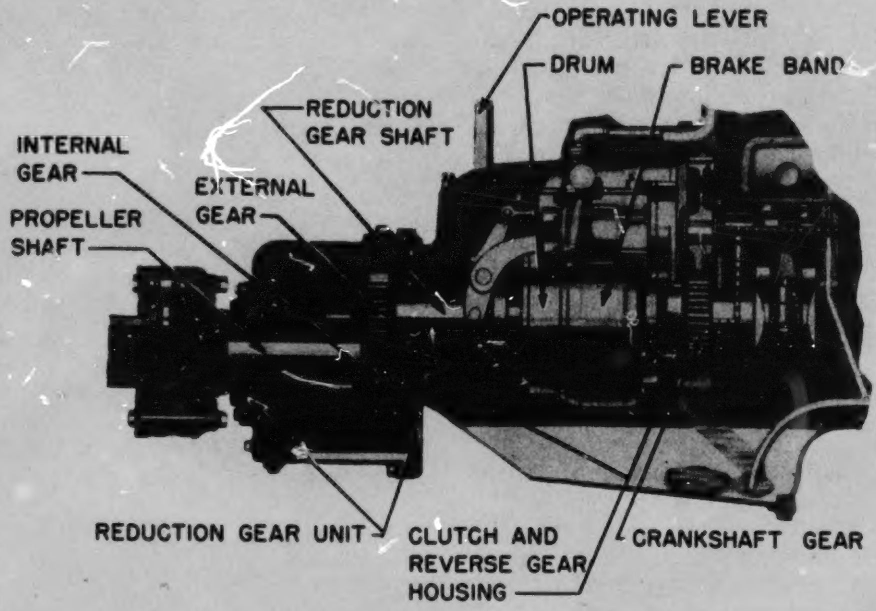
OPERATING LEVER
DRUM
BRAKE BAND
REDUCTION GEAR SHAFT
INTERNAL GEAR
EXTERNAL GEAR
PROPELLER SHAFT
REDUCTION GEAR UNIT
CLUTCH AND REVERSE GEAR HOUSING
CRANKSHAFT GEAR

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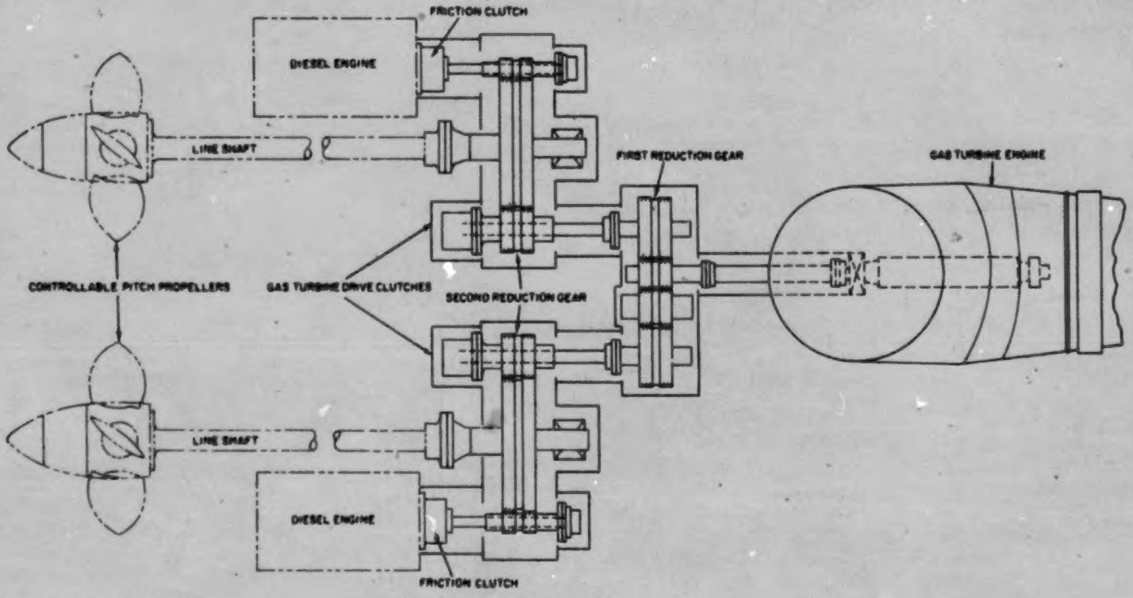
Figure 14-2.–Clutch and reverse gear assembly with attached reduction gear unit.


FRICTION CLUTCH
DIESEL ENGINE
LINE SHAFT
FIRST REDUCTION GEAR
GAS TURBINE ENGINE
CONTROLLABLE PITCH PROPELLERS
GAS TURBINE DRIVE CLUTCHES
SECOND REDUCTION GEAR
LINE SHAFT
DIESEL ENGINE
FRICTION CLUTCH

75.308X

Figure 14-3.–Example of combination diesel and gas turbine.

cruising and maneuvering in confined waters. Each diesel drives a propeller shaft independently of the other. The gas turbine is used for high speed operation. The single gas turbine drives both propeller shafts through the drive mechanism. This combination permits a large cruising range along with high speed when needed.

The Navy uses many types of reduction gears, reverse gears, and clutches. You can find additional information on any particular type in the manufacturer's technical manual.

Electric Drives

In the propulsion plants of some diesel-driven ships, there is no mechanical connection between the engine(s) and the propeller(s). In such plants, the diesel engines are connected directly to generators. The electricity produced by such an engine-driven generator is transmitted through cables to a motor. The motor is connected to the propeller shaft directly, or indirectly, through a reduction gear. When a reduction gear is included in a diesel-electric drive, the gear is located between the motor and the propeller.

The generator and the motor of a diesel-electric drive may be the alternating current (a.c.) type or the direct current (d.c.) type. Almost all diesel-electric drives used by the Navy, however, are the direct currect type. Since the speed of a d.c. motor varies directly with the voltage furnished by the generator, the control system of an electric drive is arranged so that the generator voltage can be changed at any time. An increase or decrease in generator voltage is used to control the speed of the propeller. Generator voltage may be changed electrically, by changes in engine speed, and by a combination of these methods. The controls of an electric drive may be located remotely from the engine, such as in the pilothouse.

In an electric drive the direction of rotation of the propeller is not reversed by a reverse gear. The electrical system is arranged so that the flow of current through the motor can be reversed. This reversal of current flow causes the motor to revolve in the opposite direction. Thus, the direction of rotation of the motor and of the propeller can be controlled by manipulating the electrical controls.

DIRECT DRIVES

In some marine engine installations, power from the engine is transmitted to the drive unit without a change in shaft speed; that is, by a direct drive. In a direct drive, the connection between the engine and the driven unit may consist of a "solid" coupling, a flexible coupling, or a combination of both. There may or may not be a clutch in a direct drive, depending upon the type of installation. Some installations have a reverse gear.

Solid Couplings

Solid type couplings vary considerably in design. Some solid couplings consist of two flanges bolted solidly together (fig. 14-4). In other direct drives, the driven unit is attached directly to the engine crankshaft by a nut, as in the P-250 centrifugal fire pump.

Solid couplings offer a positive means of transmitting torque from the crankshaft of an engine; however, a solid connection does not allow for any misalignment nor does it absorb

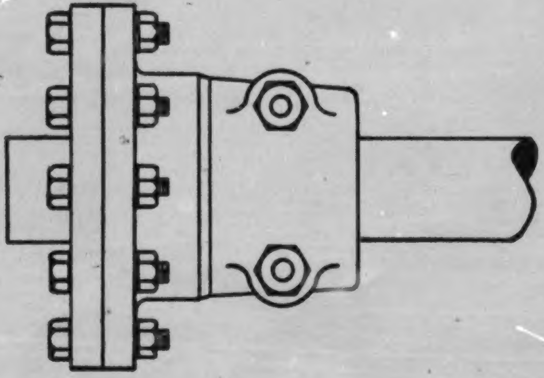


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Figure 14-4.—Flange type solid coupling.

any of the torsional vibration transmitted from the engine crankshaft.

Flexible Couplings

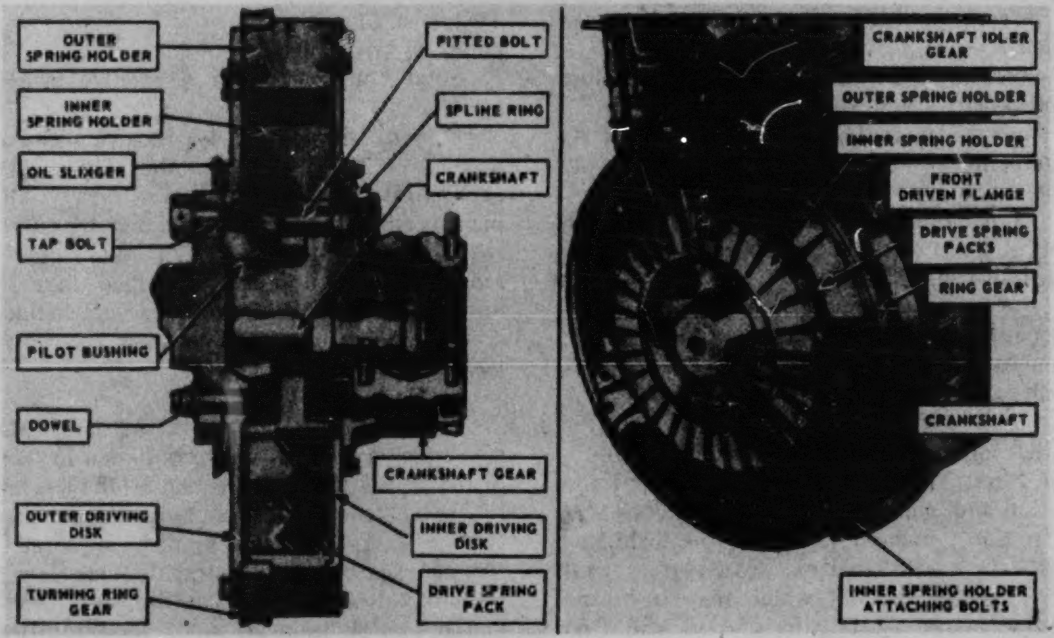
Since solid couplings do not absorb vibration and do not permit any misalignment, most direct drives consist of a flange-type coupling which is used in connection with a flexible coupling. Connections of the flexible type are common to the drives of many auxiliaries, such as engine-generator sets. Flexible couplings are also used in indirect drives to connect the engine to the drive mechanism.

The two solid halves of a flexible coupling are joined by a flexible element. The flexible element is made of rubber, neoprene, or steel springs. Two views of one type of flexible coupling are shown in figure 14-5.

This coupling has radial spring packs as the flexible element. The power from the engine is transmitted from the inner ring, or spring holder, of the coupling through a number of spring packs to the outer spring holder, or driven member. A large driving disk connects the outer spring holder to the flange on the driven shaft. The pilot on the end of the crankshaft fits into a bronze bearing on the outer driving disk to center the driven shaft. The ring gear of the jacking mechanism is pressed onto the rim of the outer spring holder.

The inner driving disk, through which the camshaft gear train is driven, is fastened to the outer spring holder. A splined ring gear is bolted to the inner driving disk. This helical, internal gear fits on the outer part of the crankshaft gear and forms an elastic drive through the crankshaft gear which rides on the crankshaft. The splined ring gear is split and the two parts are bolted together with a spacer block at each split-joint.

The parts of the coupling shown in figure 14-5 are lubricated by oil flowing from the


OUTER SPRING HOLDER
INNER SPRING HOLDER
OIL SLINGER
TAP BOLT
PILOT BUSHING
DOWEL
OUTER DRIVING DISK
TURNING RING GEAR
FITTED BOLT
SPLINE RING
CRANKSHAFT
CRANKSHAFT GEAR
INNER DRIVING DISK
DRIVE SPRING PACK
CRANKSHAFT IDLER GEAR
OUTER SPRING HOLDER
INNER SPRING HOLDER
FRONT DRIVEN FLANGE
DRIVE SPRING PACKS
RING GEAR
CRANKSHAFT
INNER SPRING HOLDER ATTACHING BOLTS

75.251

Figure 14-5.—Flexible coupling (GM 278A).

bearing bore on the crankshaft gear through the pilot bearing.

CLUTCHES, REVERSE GEARS, AND REDUCTION GEARS

Clutches may be used on direct-drive propulsion Navy engines to disconnect the engine from the propeller shaft. In small engines, clutches are usually combined with reverse gears and used for maneuvering the ship. In large engines, special types of clutches are used to obtain special coupling or control characteristics and to prevent torsional vibration.

Reverse gears are used on marine engines to reverse the direction of rotation of the propeller shaft for maneuvering the ship, without changing the direction of rotation of the engine. Reverse gears are used principally on relatively small engines. If a high-output engine has a reverse gear, the gear is used for low-speed operation only and does not have full-load and full-speed capacity. For maneuvering ships with large direct-propulsion engines, the engines are reversed.

Reduction gears are used to obtain low propeller-shaft speed with a high engine speed. The gears correlate two conflicting requirements:

(1) For minimum weight and size for a given power output, engines must have a relatively high rotative speed.

(2) For maximum efficiency, propellers must rotate at a relatively low speed, particularly where high thrust capacity is desired.

There are many types of transmissions used by the Navy. This chapter covers, in general, the operation and maintenance of transmissions that use friction, pneumatic, synchro-self-shifting fluid or hydraulic, dog-type, and electromagnetic clutches which may be found on Navy marine installations. You will find additional information on a particular unit in the manufacturer's technical manual for that specific installation.

FRICTION CLUTCHES AND GEAR ASSEMBLIES

Friction clutches are most commonly used with smaller, high-speed engines, up to 500 hp. However, certain friction clutches, in combination with a jaw-type clutch, are used with engines up to 1,400 hp; and pneumatic clutches, with a cylindrical friction surface, with engines up to 2,000 hp.

There are two general styles of friction clutches: DISK and BAND. They can be classified into DRY and WET types, depending on whether they operate with or without a lubricant.

Friction clutches are engaged by applying force-producing friction which can be obtained either by mechanically jamming the friction surfaces together by some toggle-action linkage, or through stiff springs (coil, leaf, or flat-disk type). The operation of friction clutches is covered in the sections which follow.

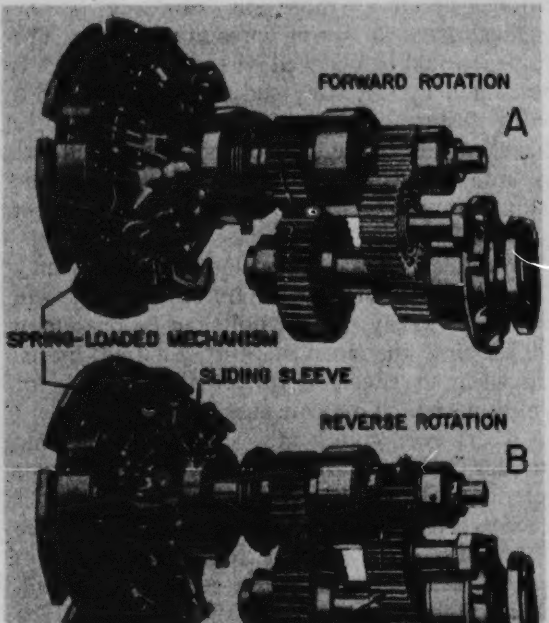
Twin-Disk Clutch and Gear Mechanism

One of the several types of transmissions used by the Navy is the Gray Marine transmission mechanism. Gray Marine high-speed diesel engines are generally equipped with a combination clutch, a reverse and reduction gear unit—all contained in a single housing at the afterend of the engine. A sectional view of this mechanism is shown in figure 14-1.

The clutch assembly of the Gray Marine transmission mechanism is contained in the part of the housing nearest the engine (the left end of fig. 14-1). It is a dry-type, twin-disk clutch with two driving disks. Each disk is connected, through shafting, to a separate reduction gear train in the afterpart of the housing. One disk and reduction train are for reverse rotation of the shaft and propeller, the other disk and reduction train are for forward rotation. The forward and reverse gear trains for Gray Marine engines are illustrated in figure 14-6. In studying figures 14-1 and 14-6 notice that the gear trains are different in the two illustrations; however, the operation of the mechanisms shown is basically the same.

CLUTCH OPERATING LEVER.–Since the gears for forward and reverse rotation of the twin-disk clutch and gear mechanism remain in mesh at all times, there is no shifting of gears. In shifting the mechanism, only the floating plate, located between the forward and reverse disks, is shifted. The shifting mechanism is a sliding sleeve, which does not rotate but has a loose sliding fit around the hollow forward shaft. A throwout fork (yoke) engages a pair of shifter blocks pinned on either side of the sliding sleeve.

The clutch operating lever moves the throwout fork, which in turn shifts the sliding sleeve lengthwise along the forward shaft. When the operating lever is placed forward, the sliding sleeve is forced backward. In this position the linkage of the spring-loaded mechanism pulls the floating pressure plate against the forward disk and causes forward rotation. When the operating lever is pulled back as far as it can go, the sliding sleeve is pushed forward. In this position, the floating pressure plate engages the reverse disk and backplate for reverse rotation.



75.252
Figure 14-6.–Forward and reverse gear trains for Gray Marine engines.

The clutch has a positive neutral which is set by placing the operating lever in a middle position. Then the sliding sleeve is also in a middle position, and the floating plate rotates freely between the two clutch disks. (The only control that the operator has is to cause the floating plate to bear heavily against either the forward disk or the reverse disk, or to put the floating plate in the positive neutral position so that it rotates freely between the two disks.)

FORWARD ROTATION.–As mentioned above, the two clutch disks shown in figure 14-1 are separated from each other by the floating plate. Let us see what happens when the floating plate presses against the forward disk. The forward disk, in turn, is pressed against the front plate, which is bolted to and rotates with the engine flywheel. The friction disk immediately begins to rotate with the front plate at engine speed. The forward disk has internal teeth; the forward sleeve has an integral external gear. The forward sleeve shaft transmits the rotation to the propeller shaft through the two-gear train, shown in part A of figure 14-6. (Notice the arrows which indicate the directions of rotation.)

REVERSE ROTATION.–Reverse rotation occurs when the floating plate is pressed against the reverse disk. In turn, the reverse disk is pressed against the back plate, which is also bolted to the engine flywheel (fig. 14-1). At engine speed, the reverse disk begins to rotate with the back plate. The reverse disk has internal teeth; the reverse sleeve has an integral external gear. The reverse shaft transmits the rotation through the three-gear train, shown in part B of figure 14-6. Notice the presence of an idler gear in the reverse-gear train. This gear reverses the direction of the propeller shaft rotation.

LUBRICATION.–The reversing gear unit is lubricated separately from the engine by its own splash system. The oil level of the gear housing should NEVER be kept over the high mark because too much oil will cause the gear unit to overheat. The oil is cooled by air blown through the baffled top cover by the rotating clutch. There are grease fittings for bearings that are not lubricated by the oil. Do not overgrease the bearings in a dry friction clutch because any excess grease that gets on the friction plates will cause slippage. To prevent binding caused by rust, use a light machine oil to lubricate clutch parts that do not have grease fittings.

OPERATIONAL ADJUSTMENTS.–Since the spring-loaded clutch-operating mechanism is pressure-set at the factory, it is not necessary to adjust the mechanism. The mechanism is designed to follow up and to compensate for wear on the friction plates. The simplest way to determine when the disks need to be replaced is to check the position of the plunger in the engaged position. The plunger is permitted to travel a specified amount in accordance with the manufacturer's instructions. The gears are keyed to their shafts, mounted on ball bearings in permanently fixed centers, and require no adjustment.

Friction Clutch Troubles

Difficulties which may necessitate repair of friction clutches will vary, depending upon the classification of the clutch (wet or dry, disk or band) and also upon the method of operation (hand, hydraulic, pneumatic, vacuum). The troubles discussed in this section–slippage and wear, freezing, and noise–are common to most friction-type clutches.

SLIPPAGE AND WEAR.–It is difficult to consider slippage and wear separately, since each can be the cause of the other, and each intensifies the other's effect. Slippage generally occurs at high engine speed when the engine is delivering the greatest torque. Slippage causes lowered efficiency, loss of power, and rapid wear of the clutch friction surfaces.

There are several possible causes of clutch slippage: wear, insufficient pressure, overload, and fouling.

Over a period of operation, extended engaging and disengaging of the surfaces will cause a normal amount of wear, and if the surfaces are rough, wear will be excessive.

When a friction clutch is being overhauled, care must be taken not to damage the bearing surfaces; small nicks must be stoned, and if the scoring is serious, the damaged surface must be refinished, or the part must be replaced. Since water has a deteriorating effect on clutch facings, every effort must be made to keep dry-type clutches free of water.

Do not engage the clutch while racing the engine. It may cause excessive wear, and it will strain the entire drive system.

Some types of friction clutches are not adjustable but are dependent upon the initial compression in the pressure springs. Twin-disk clutches, such as those on the Gray Marine engines, have a spring pressure system. The springs should be checked whenever the clutch is disassembled. Checking should be done with a spring tester; however, if none is available, a check on the free lengths of the springs will give an indication of their condition. Consult the manufacturer's technical manual for the proper values.

When an engine is overloaded, torque may be increased to such an extent that slippage will occur. Obviously, this trouble can be prevented by keeping the load within specified limits. Whenever an engine is fully loaded, watch for symptoms which indicate slippage.

A dry-type clutch may slip when the lining surfaces become fouled with oil, grease, or water. Oil or grease on the clutch surfaces is usually the result of careless maintenance procedures, such as using too much grease in lubricating or overfilling the gear case with oil. When oil in a gear case foams, there will be leakage from the shaft bearings. Foaming may be caused by air leaks in the oil suction line or by overfilling. When foaming occurs, inspect all lube oil lines for air leaks, and check for proper oil level.

When filling a reduction gear case, add only enough oil to bring the level up to the FULL mark. Do not add or measure oil when the unit is in operation, because you will not get an accurate oil reading.

In a twin-disk clutch installation, an oil leak in the rear main bearing of the engine may cause oil to appear on the clutch surfaces. The leakage may be caused by excessive bearing clearance, overfilling of the engine crankcase, a plugged crankcase breather cap, or excessive piston blowby. The crankcase breather cap must be cleaned periodically to prevent it from becoming clogged.

Another source of fouling is grease that may get on a dry-type clutch during overhaul. Do not handle the parts with greasy hands, and remove any grease deposits with an approved cleaner. For the pneumatically operated friction clutches, where rubber parts are used, use only a dry cloth on clutch facings.

When there is clutch slippage, immediately take steps to correct the trouble. The clutch surfaces are probably worn, so check the thickness of the clutch linings. When a lining is worn excessively, replace it; tightening the adjusting device will not correct excessive surface wear. Instead, such adjustments may lead to the scoring of the mating clutch surfaces.

FROZEN CLUTCH.–When a clutch fails to disengage, it is said to be "frozen." Failure to disengage may be caused by a defective clutch mechanism or by water in the clutch linings.

When a clutch becomes frozen, inspect the operating mechanism. Check the control rods for obstructions or loose connections, and check for excessive clearances in the throwout bearing pressure plate, the pivots, and the toggles. In a twin-disk clutch, warped disks will cause the clutch to freeze. (Warped disks are caused by extended running in neutral position.)

If a dry-type clutch has molded-type clutch linings, moisture will cause the linings to swell and to become soft. When this occurs, many linings tend to stick to the mating surfaces. Every effort should be made to prevent moisture from getting to the clutch linings. If a molded lining becomes wet, let it dry in the disengaged position. Allowing the linings to dry in the engaged position increases the possibility of sticking.

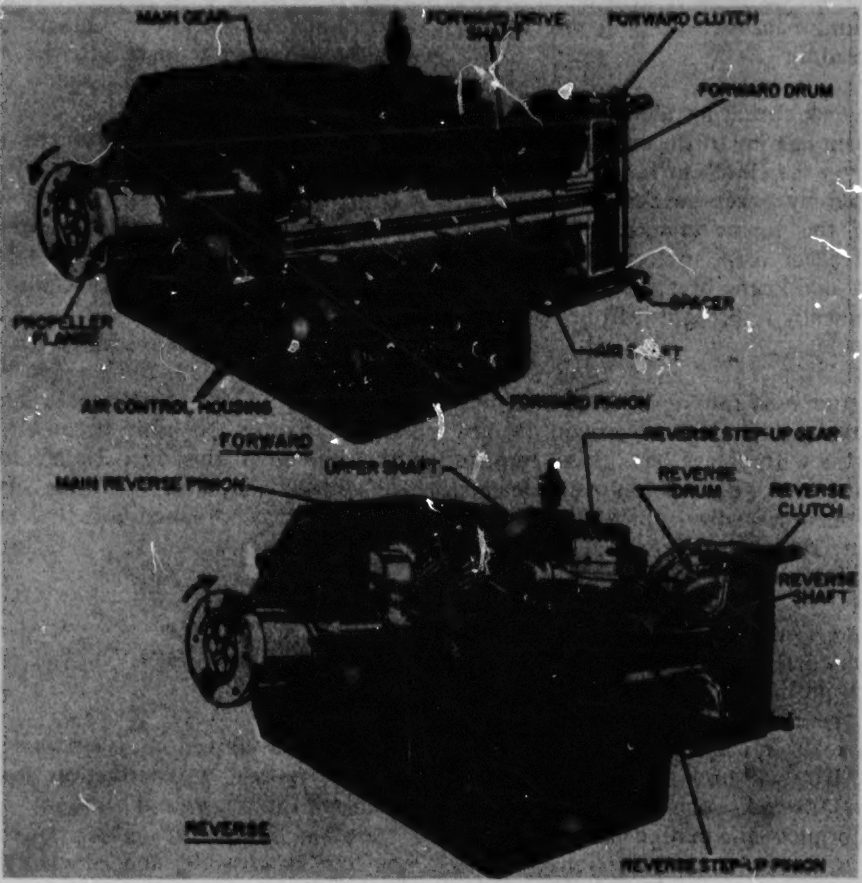
CLUTCH NOISE.–Dry-type clutches may produce a chattering noise when the clutch is being engaged. Excessive clutch chatter may cause damage to the reverse and reduction gears, and may cause the clutch linings to break loose, resulting in complete clutch failure.

The principal cause of clutch chatter is oil, grease, or water on the linings. Every possible precaution should be taken to keep oil, grease, or water out of the unit, because replacement of the linings is the only satisfactory means of repair. All metal parts of the clutch must be cleaned in accordance with the manufacturer's instructions.

AIRFLEX CLUTCH AND GEAR ASSEMBLY

On the larger diesel-propelled ships, the clutch, reverse, and reduction gear unit has to transmit an enormous amount of power. To maintain the weight and size of the mechanism as low as possible, special clutches have been designed for large diesel installations. One of these is the airflex clutch and gear assembly used with General Motors 12-567A engines on LST's.

The airflex clutch and gear assembly shown in figure 14-7 consists of two clutches, one for forward rotation and one for reverse rotation. The clutches are bolted to the engine flywheel by a steel SPACER, so that they both rotate with the engine at all times at any engine speed. Each clutch has a flexible tire (gland) on the inner side of a steel shell. Before the tires are inflated, they will rotate out of contact with the drums, which are keyed to the forward and reverse drive shafts. When air under pressure (100 psi) is forced into one of the tires, the inside diameter of the clutch decreases. This causes the friction blocks on the inner tire surface to come in contact with the clutch drum, locking the drive shaft with the engine.


MAIN GEAR
FORWARD DRIVE SHAFT
FORWARD CLUTCH
FORWARD DRUM
PROPELLER FLANGE
SPACER
AIR SHAFT
AIR CONTROL HOUSING
FORWARD PINION
FORWARD
REVERSE STEP-UP GEAR
UPPER SHAFT
MAIN REVERSE PINION
REVERSE DRUM
REVERSE CLUTCH
REVERSE SHAFT
REVERSE
REVERSE STEP-UP PINION

75.247

Figure 14-7.—Clutch and reverse-reduction gear assembly.

Forward Rotation

The parts of the airflex clutch which give the propeller ahead rotation are illustrated in the upper view of figure 14-7. The clutch tire nearest the engine (forward clutch) is inflated to contact and drive the forward drum with the engine. The forward drum is keyed to the forward drive shaft, which carries the double helical forward pinion at the afterend of the gear box. The forward pinion is in constant mesh with the double helical main gear, which is keyed to the propeller shaft. By following through the gear train, you can see that, for ahead motion, the propeller rotates in a direction opposite to the engine's rotation.

Reverse Rotation

The parts of the airflex clutch which give the propeller astern rotation are illustrated in the lower view of figure 14-7. The reverse clutch is inflated to engage the reverse drum, which is then driven by the engine. The reverse drum is keyed to the short reverse shaft, which surrounds the forward drive shaft. A large reverse step-up pinion transmits the motion to the large reverse step-up gear on the upper shaft.

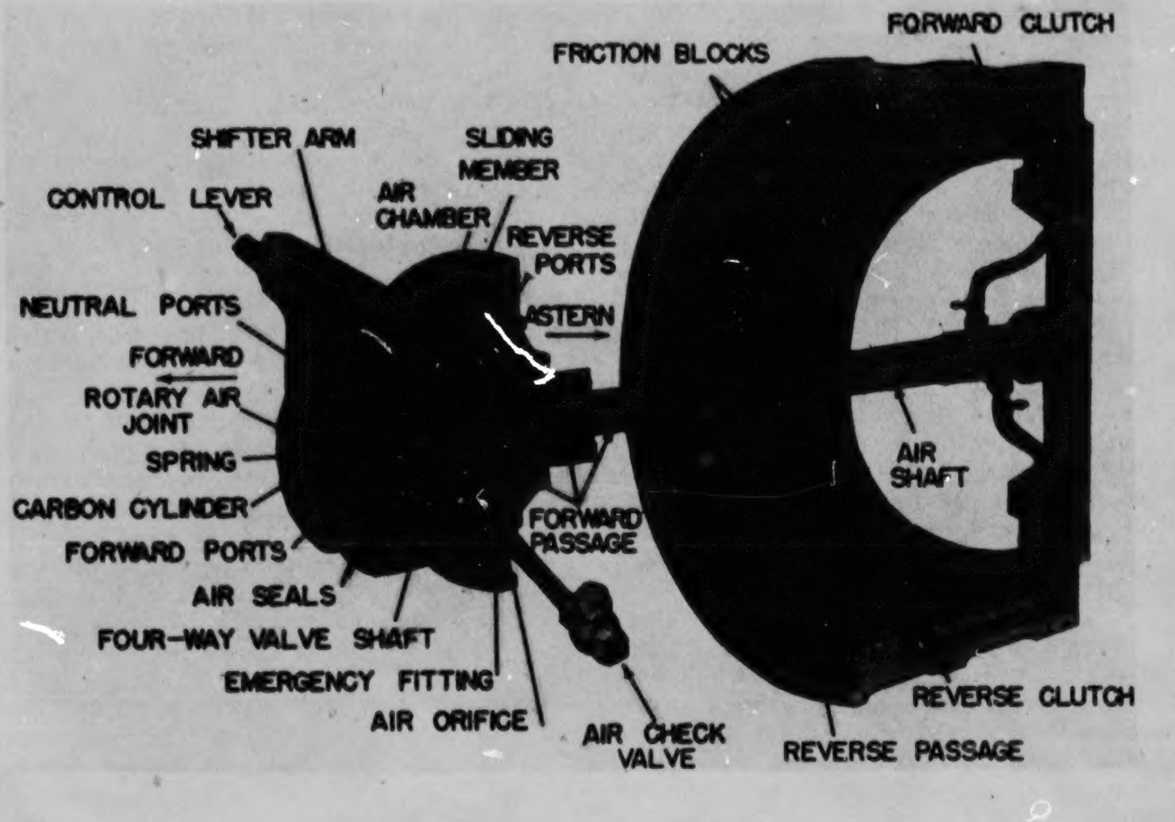
The upper shaft rotation is opposite to the engine's rotation. The main reverse pinion on the upper shaft is in constant mesh with the main gear. By tracing through the gear train, you will see that, for reverse rotation, the propeller rotates in the same direction as the engine.

The diameter of the main gear of the airflex clutch is approximately 2 1/2 times as great as that of the forward and reverse pinions. Thus, there is a speed reduction of 2 1/2 to 1 from either pinion to the propeller shaft.

Since the forward and main reverse pinions are in constant mesh with the main gear, the set of gears that is not clutched in will rotate as idlers driven from the main gear. The idling gears rotate in a direction opposite to their rotation when carrying the load. For example, with the forward clutch engaged, the main reverse pinion rotates in a direction opposite to its rotation for astern motion (note the dotted arrow in the upper view of figure 14-7). Since the drums rotate in opposite directions, a control mechanism is installed to prevent the engagement of both clutches simultaneously.

Airflex Clutch Control Mechanism

The airflex clutch is controlled by an operating lever which works the air control housing, located at the afterend of the forward pinion shaft. The control mechanism, shown with the airflex clutches in figure 14-8, directs the high-pressure air into the proper paths to inflate the clutch glands (tires). The air shaft, which connects the control mechanism to the clutches, passes through the forward drive shaft.


FORWARD CLUTCH
FRICTION BLOCKS
SHIFTER ARM
SLIDING MEMBER
CONTROL LEVER
AIR CHAMBER
REVERSE PORTS
NEUTRAL PORTS
ASTERN
FORWARD
ROTARY AIR JOINT
SPRING
AIR SHAFT
CARBON CYLINDER
FORWARD PASSAGE
FORWARD PORTS
AIR SEALS
FOUR-WAY VALVE SHAFT
EMERGENCY FITTING
REVERSE CLUTCH
AIR ORIFICE
AIR CHECK VALVE
REVERSE PASSAGE

75.257

Figure 14-8.—Airflex clutches and control valves.

The supply air enters the control housing through the air check valve and must pass through the small air orifice. The restricted orifice delays the inflation of the clutch to be engaged during shifting from one direction of rotation to the other. The delay is necessary to allow the other clutch to be fully deflated and out of contact with its drum before the inflating clutch can make contact with its drum.

The supply air goes to the rotary air joints in which a hollow carbon cylinder is held to the valve shaft by spring tension, preventing leakage between the stationary carbon seal and rotating air valve shaft. The air goes from the rotary joint to the four-way air valve. The sliding-sleeve assembly of the four-way valve can be shifted endwise along the valve shaft by operating the control lever.

When the shifter arm on the control lever slides the valve assembly away from the engine, air is directed to the forward clutch. The four-way valve makes the connection between the air supply and the forward clutch. There are eight neutral ports which connect the central air supply passage in the valve shaft with the sealed air chamber in the sliding member. In the neutral position of the four-way valve, as shown in figure 14-8, the air chamber is a dead end for the supply air. With the shifter arm in the forward position the sliding member uncovers eight forward ports, which connect with the forward passages conducting the air to the forward clutch. The air now flows through the neutral ports, air chamber, forward ports, and forward passages to inflate the forward clutch gland. As long as the shifter arm is in the forward position, the forward clutch will remain inflated, and the entire forward air system will remain at a pressure of 100 psi.

At this point, let us assume that the bridge signals you to reverse the propeller. You should pull the operating lever back to neutral position and hold it there for 2 or 3 seconds (as a safety factor). Then pull the lever to the reverse idling position and wait about 7 seconds, after which the reverse clutch is fully engaged. Then you can increase the reverse speed to whatever the bridge has ordered.

Why was it necessary to pause at neutral and at reverse idling positions, and what has happened in the air control and clutch mechanism? When you shift to neutral, the forward ports are uncovered, and the compressed air from the forward clutch and passage vents to the atmosphere. In deflating either clutch, the air is vented through eight ports approximately the same size as the air orifice, so that deflating either clutch actually requires 1 or 2 seconds. Pausing for 2 or 3 seconds at neutral allows enough time for the forward clutch to deflate and disengage before you start inflating the reverse clutch.

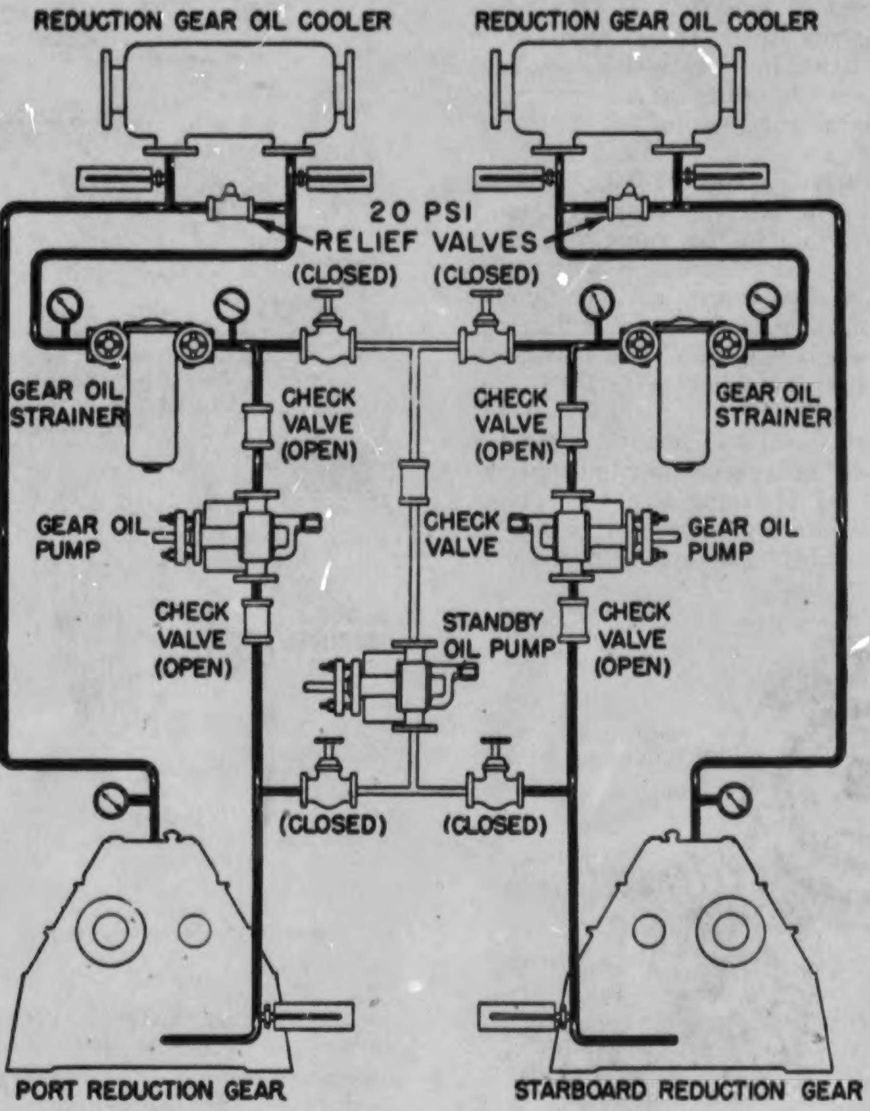
When you shift to reverse idling, the air chamber comes over the eight reverse ports which open to the central reverse passage in the air shaft. The compressed air begins to inflate the reverse clutch immediately; the inflating air must pass through the single air orifice in the supply line, causing a delay of about 7 seconds to fully inflate a clutch. When the clutch is in the reverse idling position, wait until the reverse clutch is fully engaged before increasing the speed to prevent damaging the clutch (by slipping). It is impossible to have both clutches engaged at the same time.

Lubrication

Most large gear units have a separate lubrication system. The lubricating system for the General Motors 12-567A unit is shown in figure 14-9. The oil is picked up from the gear box by an electric-driven, gear-type lubricating oil pump and is sent through a strainer and cooler. After being cleaned and cooled, the oil is returned to the gear box to cool and lubricate the gears. In twin installations, such as shown in figure 14-9, a separate pump is used for each unit and a standby pump is interconnected for emergency use.

HYDRAULIC CLUTCHES (COUPLINGS)

The fluid clutch (coupling) is widely used in Navy ships. A hydraulic coupling eliminates the need for a mechanical connection between the engine and the reduction gears. Power is transmitted through hydraulic couplings very


REDUCTION GEAR OIL COOLER
REDUCTION GEAR OIL COOLER
20 PSI
RELIEF VALVES
(CLOSED)
(CLOSED)
GEAR OIL STRAINER
CHECK VALVE (OPEN)
CHECK VALVE (OPEN)
GEAR OIL STRAINER
GEAR OIL PUMP
CHECK VALVE
GEAR OIL PUMP
CHECK VALVE (OPEN)
STANDBY OIL PUMP
CHECK VALVE (OPEN)
(CLOSED)
(CLOSED)
PORT REDUCTION GEAR
STARBOARD REDUCTION GEAR

75.258

Figure 14-9.—Schematic diagram of reverse gear lubrication system (GM 12-567A).

efficiently (97%) without transmitting torsional vibrations or load shocks from the engine to the reduction gear. The power loss from the small amount of slippage is transformed into heat which is absorbed by the oil in the system. Some slippage is necessary for operation of the hydraulic coupling, since torque transmission depends on relative motion between the two rotors.

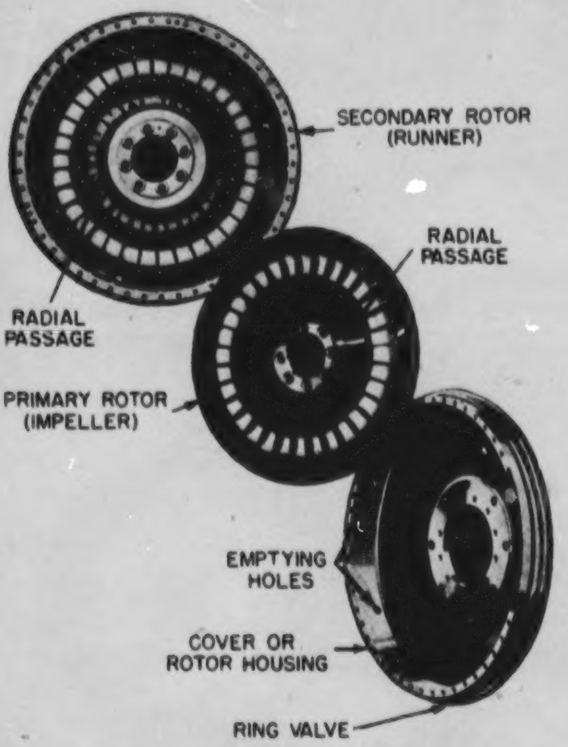
Hydraulic Coupling Assemblies

The two rotors and the oil-sealing cover of a typical hydraulic coupling are shown in figure

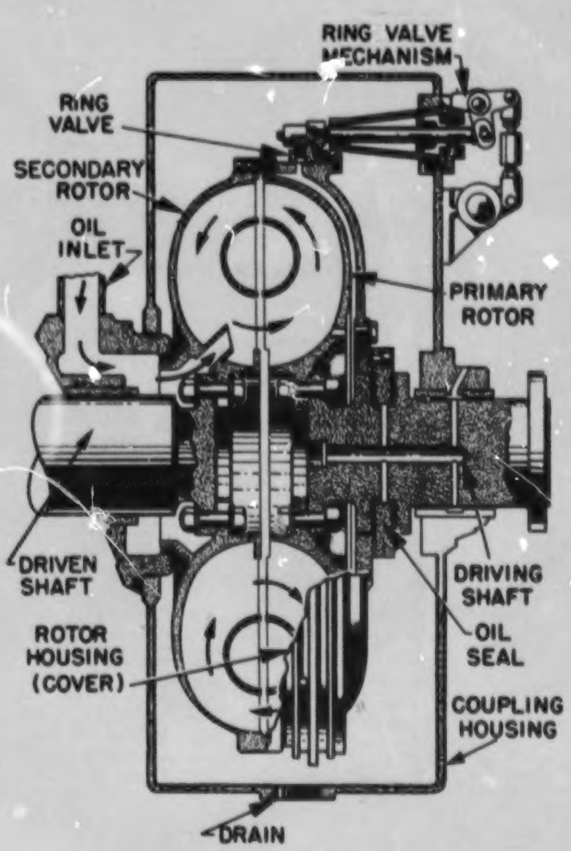
14-10. The primary rotor (impeller) is attached to the engine crankshaft. The secondary rotor (runner) is attached to the reduction gear pinion shaft. The cover is bolted to the secondary rotor and surrounds the primary rotor.

Before proceeding with the assembly of the rotors and the shafts in the coupling housing, study the structure of the rotors themselves. Each rotor is shaped concave with radial partitions. A shallow trough is welded into the partitions around the inner surface of the rotor. The radial passages tunnel under this trough (as indicated by the white arrows in fig. 14-10).

When the coupling is assembled, the two rotors are placed facing each other to complete a circle (fig. 14-11). The rotors do not quite touch each other; the clearance between them is 1/4 to 5/8 inch, depending on the size of the coupling.


SECONDARY ROTOR (RUNNER)
RADIAL PASSAGE
RADIAL PASSAGE
PRIMARY ROTOR (IMPELLER)
EMPTYING HOLES
COVER OR ROTOR HOUSING
RING VALVE

5.33
Figure 14-10.—Runner, impeller, and cover of hydraulic coupling.


RING VALVE MECHANISM
RING VALVE
SECONDARY ROTOR
OIL INLET
PRIMARY ROTOR
DRIVEN SHAFT
DRIVING SHAFT
OIL SEAL
ROTOR HOUSING (COVER)
COUPLING HOUSING
DRAIN

75.260
Figure 14-11.—Hydraulic coupling assembly.

The curved radial passages of the two rotors are opposite each other, so that the outer passages combine to make a circular passage except for the small gaps between the rotors.

In the hydraulic coupling assembly, shown in figure 14-11, the driving shaft is secured to the engine crankshaft and the driven shaft goes to the reduction gear box. The oil inlet admits oil directly to the rotor cavities which become completely filled. The rotor housing is bolted to the secondary rotor and has an oil-sealed joint with the driving shaft. A ring valve, going entirely around the rotor housing, can be operated by the ring valve mechanism to open or close a series of emptying holes (fig. 14-11) in the rotor housing. When the ring valve is opened, the oil will fly out from the rotor housing into the coupling housing, draining the coupling completely in 2 or 3 seconds. Even when the ring valve is closed, some oil leaks out into the coupling housing, and additional oil enters through the inlet. From the coupling housing, the oil is drawn by a pump to a cooler, then sent back to the coupling.

Another coupling assembly used in several Navy ships is the hydraulic coupling with PISTON TYPE quick-dumping valves, shown in figure 14-12. In this coupling, in which the operation is similar to the one described above, a series of piston valves, around the periphery of the rotor housing, are normally held in the closed position by springs. By means of air or oil pressure admitted to the valves, as shown in figure 14-12, the pistons are moved axially to uncover drain ports, allowing the coupling to empty. The piston-valve clutching is used where extremely rapid declutching is not required. It offers greater simplicity and lower cost than the ring-valve coupling.

Another type of self-contained unit for certain diesel-engine drives is the SCOOP CONTROL COUPLING, shown in figure 14-13. In couplings of this type, the oil is picked up by one of two scoop tubes (one tube for each direction of rotation), mounted on the external manifold. Each scoop tube contains two passages: a smaller one (outermost) which handles the normal flow of oil for cooling and lubrication and a larger one which rapidly transfers oil from the reservoir directly to the working circuit.

The scoop tubes are operated from the control stand through a system of linkages. As one tube moves outward from the shaft centerline and into the oil annulus, the other tube is being retracted.

Four spring-loaded centrifugal valves are mounted on the primary rotor. These valves are arranged to open progressively as the speed of the primary rotor decreases. The arrangement provides the necessary oil flow for cooling as it is required. Quick-emptying piston valves are provided to rapidly empty the circuit when the scoop tube is withdrawn from contact with the rotating oil annulus.

Under normal circulating conditions, oil fed into the collector ring passes into the piston valve control tubes. These tubes and connecting passages conduct oil to the outer end of the pistons. The centrifugal force of the oil in the control tube holds the piston against the valve port, thus sealing off the circuit. When the scoop tube is withdrawn from the oil annulus in the reservoir, the circulation of oil will be interrupted, and the oil in the control tubes will be discharged through the orifice in the outer end of the piston housing. This releases the pressure on the piston and allows it to move outward, thus opening the port for rapid discharge of oil. Resumption of oil flow from the scoop tube will fill the control tubes, and the pressure will move the piston to the closed position.

Principles of Operation

Now you can see what happens in the coupling when the engine is started and the coupling is filled with oil. The primary rotor turns with the engine crankshaft. As the primary rotor turns, the oil in its radial passages flows outward under centrifugal force. (See arrows in fig. 14-11.) This forces oil across the gap at the outer edge of the rotor and into the radial passages of the secondary rotor, where the oil flows inward. The oil in the primary rotor is not only flowing outward, but is also rotating. As the oil flows over and into the secondary rotor, it strikes the radial blades in the rotor.

The secondary rotor soon begins to rotate and pick up speed, but it will always rotate more slowly than the primary rotor because of drag on the secondary shaft. Therefore, the centrifugal force of the oil in the primary rotor will always be greater than that of the oil in the secondary rotor. This causes a constant flow from the primary rotor to the secondary rotor at the outer ends of the radial passages and from the secondary rotor to the primary rotor at the inner ends.

Hydraulic Coupling Troubles

Troubles which may be encountered with a quick-dumping type hydraulic coupling are: DUMPING WHILE UNDER LOAD or EXCESSIVE SLIPPAGE. These troubles are generally caused by the plugging of the pressure

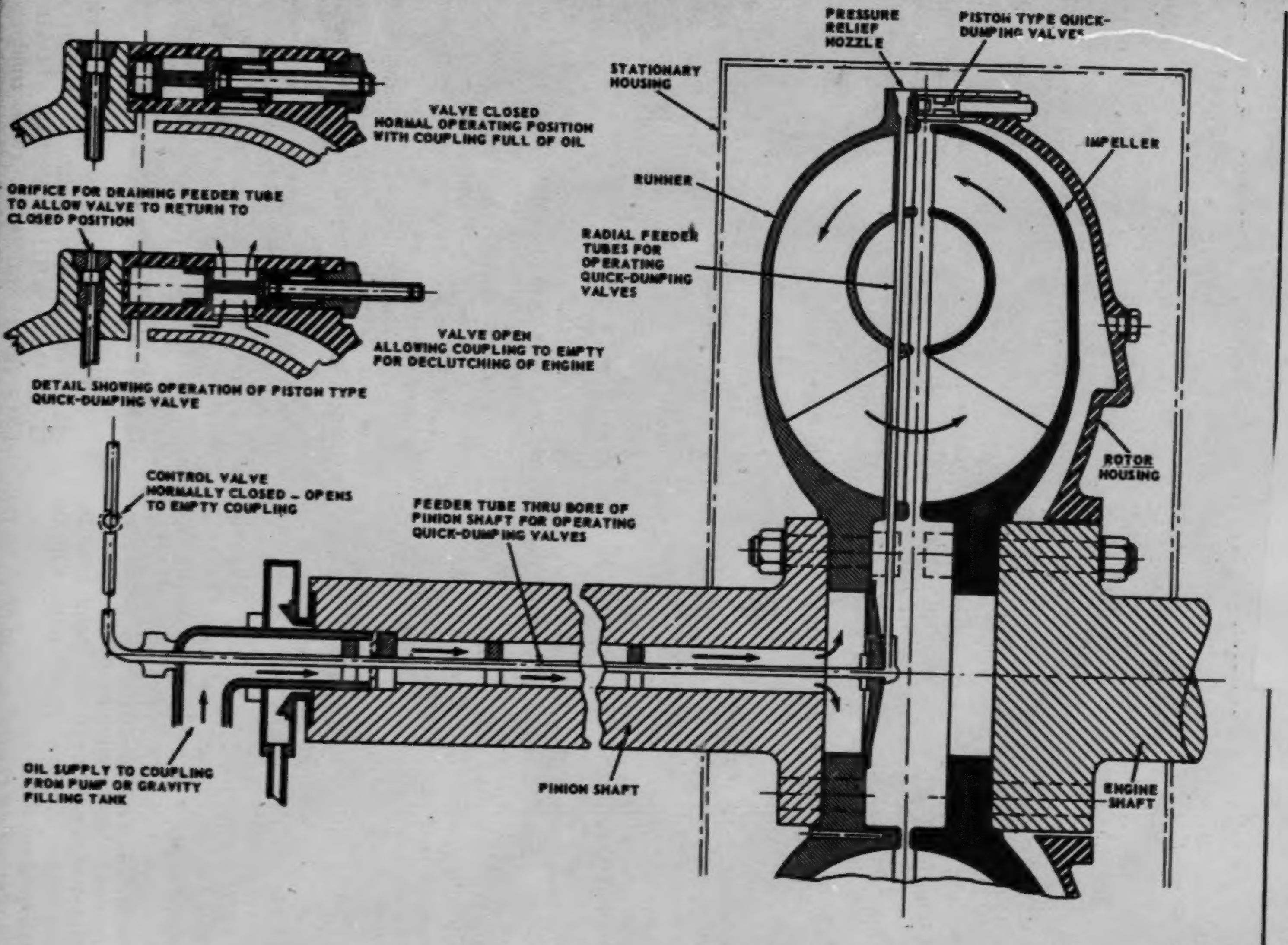
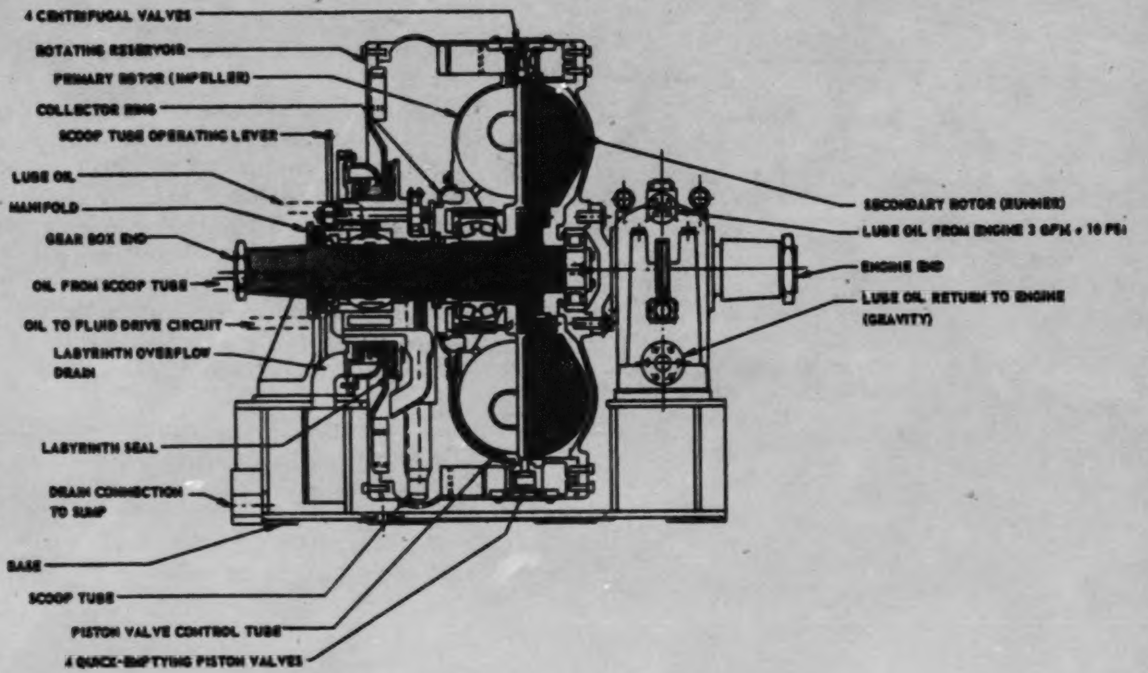

PRESSURE RELIEF NOZZLE
PISTON TYPE QUICK-DUMPING VALVES
STATIONARY HOUSING
VALVE CLOSED NORMAL OPERATING POSITION WITH COUPLING FULL OF OIL
IMPELLER
RUNNER
ORIFICE FOR DRAINING FEEDER TUBE TO ALLOW VALVE TO RETURN TO CLOSED POSITION
RADIAL FEEDER TUBES FOR OPERATING QUICK-DUMPING VALVES
VALVE OPEN ALLOWING COUPLING TO EMPTY FOR DECLUTCHING OF ENGINE
DETAIL SHOWING OPERATION OF PISTON TYPE QUICK-DUMPING VALVE
ROTOR HOUSING
CONTROL VALVE NORMALLY CLOSED – OPENS TO EMPTY COUPLING
FEEDER TUBE THRU BORE OF PINION SHAFT FOR OPERATING QUICK-DUMPING VALVES
OIL SUPPLY TO COUPLING FROM PUMP OR GRAVITY FILLING TANK
PINION SHAFT
ENGINE SHAFT
75.291X

Figure 14-12.—Hydraulic coupling with piston-type quick-dumping valves.


4 CENTRIFUGAL VALVES
ROTATING RESERVOIR
PRIMARY ROTOR (IMPELLER)
COLLECTOR RING
SCOOP TUBE OPERATING LEVER
LUBE OIL
MANIFOLD
GEAR BOX END
OIL FROM SCOOP TUBE
OIL TO FLUID DRIVE CIRCUIT
LABYRINTH OVERFLOW DRAIN
LABYRINTH SEAL
DRAIN CONNECTION TO SUMP
BASE
SCOOP TUBE
PISTON VALVE CONTROL TUBE
4 QUICK-EMPTYING PISTON VALVES
SECONDARY ROTOR (RUNNER)
LUBE OIL FROM ENGINE 3 GPM • 10 PSI
ENGINE END
LUBE OIL RETURN TO ENGINE (GRAVITY)

75.262

Figure 14-13.–Scoop control hydraulic coupling.

relief nozzles located in the periphery of the secondary rotors (fig. 14-12). These nozzles consist of drilled Allen setscrews, mounted in the secondary rotor at the ends of the radial tubes that feed air or oil to the dumping valves. The nozzles permit the feeder tubes to drain when the air or oil supply valve is closed, thus allowing the dumping valve to return to the closed position. The nozzles also permit the draining of any oil that has leaked past the control valve when shut.

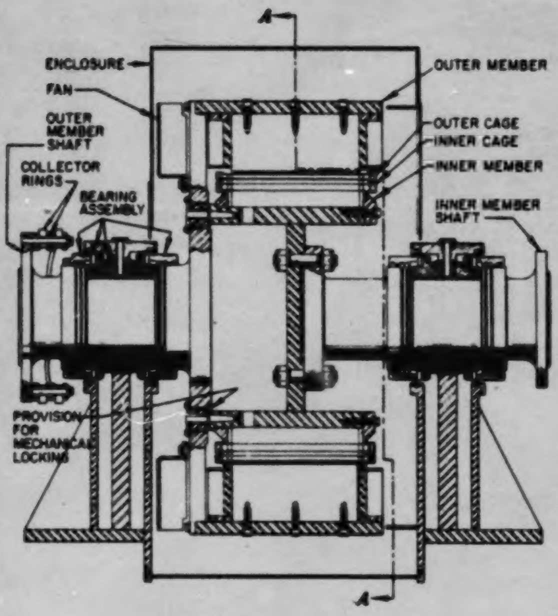
There are also leak-off nozzles in the periphery of the secondary rotor at the base of the dumping valves. The leak-off nozzles serve as flushing exits for the valves and allow a continual flow of oil past the inlet port of the dumping valves. The oil washes away any particles of foreign matter that may have a tendency to collect as a result of the centrifugal action of the coupling.

The best way to prevent a hydraulic coupling from dumping while under load is to keep the oil system free from foreign matter. Gasket compound and shreds of copper from oil tube packings often cause trouble. Every possible precaution must be taken to keep the oil system clean from foreign material. To aid in this, the system has a strainer which effectively catches, or traps, most of the foreign matter that may reach the nozzles. All nozzles must be blown out during each overhaul.

If nozzles become clogged during operation, it is possible to clear them by operating the dumping control several times. This action may blow the obstruction through the nozzle opening. If this method fails, it will be necessary to secure the engine and remove and clean the nozzles.

INDUCTION COUPLINGS

Couplings of the induction type are used in some ships in the Navy. (See fig. 14-14.) These couplings–in which the induced current appears as eddy currents–are used to transmit torque from the prime mover to variable frequency



75.263

Figure 14-14.—Induction coupling.

generators and are also used in propulsion systems. The excitation current is induced into the coils of the outer members through collector rings and brushes. When used in propulsion systems, the induction coupling provides torsional flexibility between the prime mover and the propeller shafts. Instant disconnecting is accomplished by deenergizing the coupling excitation circuit. The induction coupling limits maximum torque by pulling out of step when excessive torque is applied. On installations that have more than one engine per shaft, the induction coupling permits rapid maneuvering by allowing selection of either forward or reverse running engines; the coupling allows for a small amount of misalignment.

In operating equipment that has induction couplings, observe the following directions and precautions.

1. Do NOT attempt to alter plant performance by changing control settings to settings other than those recommended in the manufacturer's technical manual.

2. Ensure that the coupling does not overheat because of insufficient ventilation when the fields rotate at slow speeds.

3. Ensure that proper alignment is maintained (although most clutches of this type are capable of operating satisfactorily with a limited amount of misalignment).

4. Be thoroughly familiar with the means to permit the rotating members to be mechanically coupled in the event of total failure of the coupling or excitation system.

5. Be thoroughly familiar with any interlocks which serve to PREVENT:

a. Operation at reduced excitation EXCEPT when the prime mover is operating at specified reduced speeds.

b. Excitation of the field windings UNLESS the throttle control is in the proper position.

c. Excitation of the field windings UNLESS the shaft turning gear and shaftlocking devices are disengaged.

d. Excitation of the field windings at a time when the clutch would turn the driven gear counter to the direction in which it is already being driven by another coupling or clutch.

DOG CLUTCHES

Dog type clutches ensure a positive drive without slippage and with a minimum amount of wear (fig. 14-15). Dog clutches perform basically the same function as friction clutches in that they allow the engine shaft to be disconnected from the propeller shaft.

In some installations a friction clutch is used in conjunction with the dog clutch. The friction clutch (or synchronizing clutch) synchronizes the speed of the shafts and then the dog clutch is engaged. The engagement of the dog clutch eliminates any slippage and holds wear to a minimum on the friction clutch. A combination friction and dog clutch is shown in figure 14-16.

Any difficulty encountered in engaging the dog clutch will probably be due to burrs on the

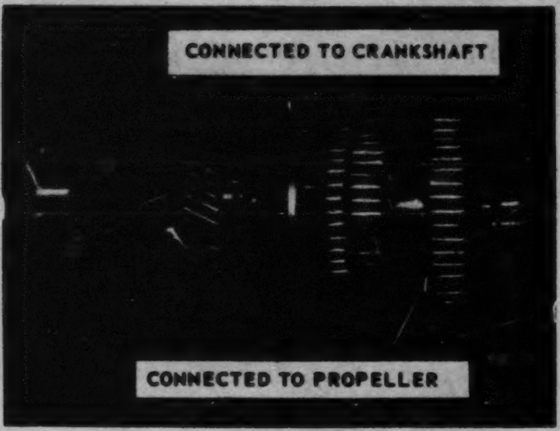


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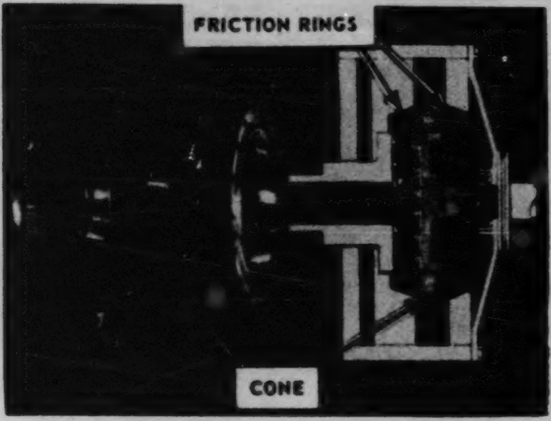
Figure 14-15.—Dog clutches.



75.265

Figure 14-16.—The synchronizing clutch.

dogs or to misalignment of the mating parts. The dogs may become burred through normal usage. Disassemble the clutch and dress down the burrs with a small handgrinder. When the damage is extensive and you cannot satisfactorily remove the burrs by grinding, replace the parts. If the difficulty in engaging a dog clutch is intermittent, misalignment is probably the cause. When this condition exists, try disengaging the clutch fully and then engaging it again. It may be that the mating dogs are prevented from shifting their relative positions by the synchronizers used to aid in bringing the two shafts to equal speed. Releasing the pressure on the engaging mechanism will usually permit relative motion between the mating dogs.

SYNCHRO-SELF-SHIFTING CLUTCH (SSS)

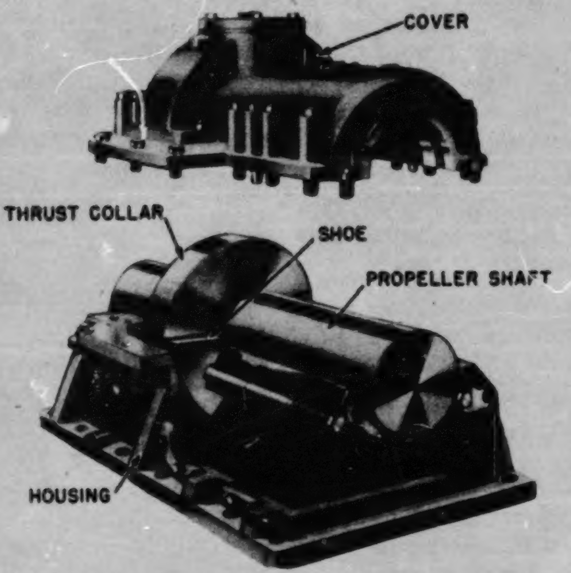
An SSS clutch is a positive, tooth-type overrunning clutch which is self-engaging when the speeds of the driving and driven shafts pass through synchronism. Engagement and disengagement are completely automatic. The clutch begins to disengage immediately when there is a reversal of torque. Satisfactory operation of the SSS clutch is not dependent on servo mechanisms or controls with interlocks.

BEARINGS

A propeller exerts a thrust on a ship which it is driving through the water. The axial thrust through the propeller shaft has to be taken up somewhere along the shaft. Therefore, a THRUST BEARING is generally installed at the forward end.

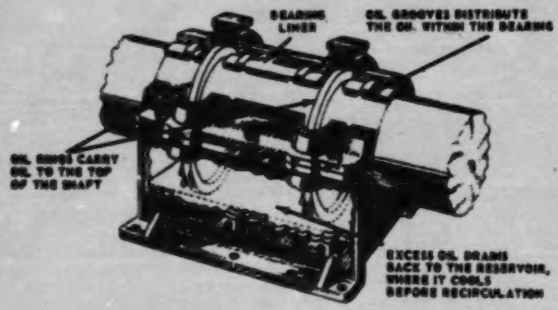
In the reduction and reverse gear units described in this chapter, a thrust bearing is mounted in the gear box. This is the usual setup on smaller ships. The most widely used is the Kingsbury thrust bearing.

A two-shoe Kingsbury thrust bearing is shown in figure 14-17. (The upper shoe is removed in this illustration.) The bearing consists of a thrust collar on the propeller shaft and two stationary thrust shoes, one on either side of the collar. The shoes are adjustable and are secured to the bearing housing which is fixed to the ship's frame. Any forward or reverse thrust on the shaft is taken up by the bearing and transmitted to the ship's structure. The collar and shoes are pressure-lubricated or run in a bath of oil. It is most important to have the collar pressure equally distributed on the shoes and to use the proper grade of lubricating oil. Detailed information concerning the maximum


COVER
THRUST COLLAR
SHOE
PROPELLER SHAFT
HOUSING

75.266

Figure 14-17.—Kingsbury thrust bearing.


BEARING LINER
OIL GROOVES DISTRIBUTE THE OIL WITHIN THE BEARING
OIL RINGS CARRY OIL TO THE TOP OF THE SHAFT
EXCESS OIL DRAINS BACK TO THE RESERVOIR, WHERE IT COOLS BEFORE RECIRCULATION

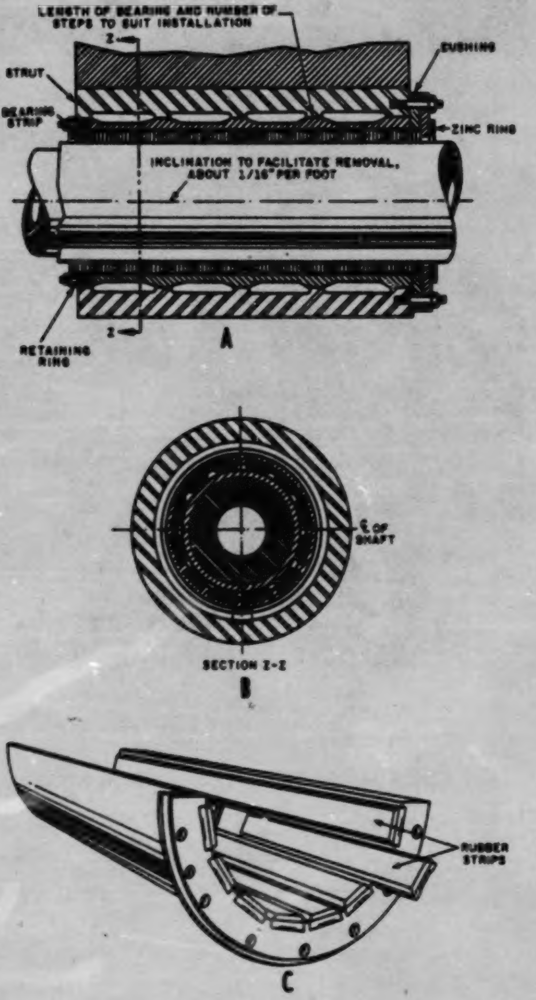
47.39X

Figure 14-18.—Spring bearing.

and minimum allowable oil clearances on thrust bearings may be obtained from either the manufacturer's technical manuals or blueprints.

Bearings that support the propulsion line shafting and are located inside the hull of the ship are called line shaft bearings or SPRING BEARINGS. These bearings are of the ring oiled, babbitt-faced, spherical-seated, shell type. Figure 14-18 illustrates the arrangement of a spring bearing. The bearing is designed to align itself to support the weight of the shafting.

A STRUT BEARING is shown in figure 14-19. The strut bearing has a composition bushing which is split lengthwise into two halves. The outer surface of the bushing is machined with steps to bear on machined loadings in the bore of the strut. One end is bolted to the strut. The shell of the strut


LENGTH OF BEARING AND NUMBER OF STEPS TO SUIT INSTALLATION
Z
STRUT
BEARING STRIP
BUSHING
ZINC RING
INCLINATION TO FACILITATE REMOVAL, ABOUT 1/16" PER FOOT
RETAINING RING
Z
A
℄ OF SHAFT
SECTION Z-Z
B
RUBBER STRIPS
C

47.41

Figure 14-19.—Strut bearing.

bearings is bronze lined with a material which will be slippery when wet with water. The shells are normally grooved lengthwise to receive strips of composition faced with rubber or synthetic rubber compounds as bearing materials. In some naval craft, resin bonded composition bearings or full molded rubber faced bearings are used.

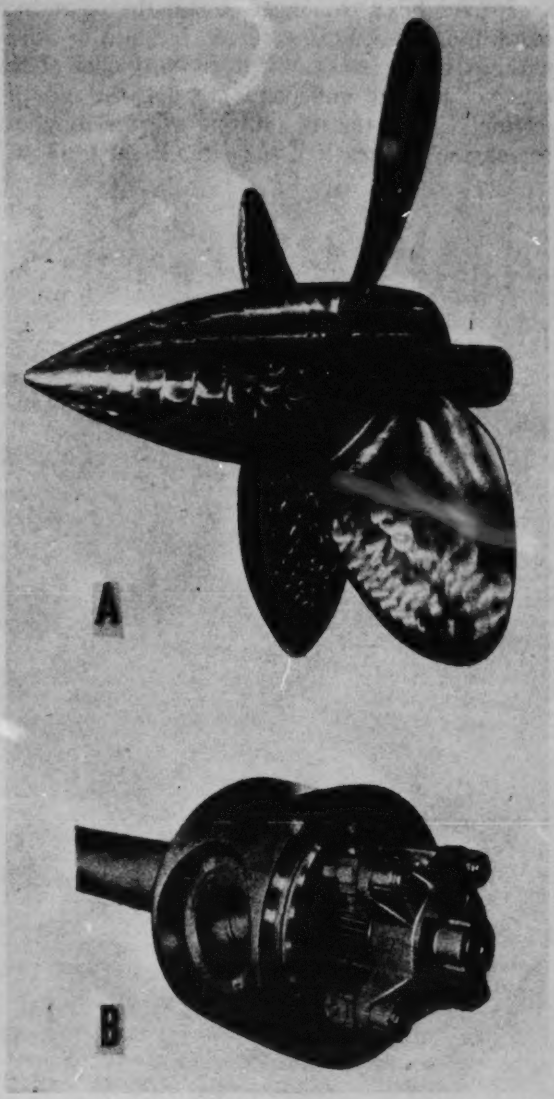
CONTROLLABLE PITCH PROPELLERS

Controllable pitch propellers (fig. 14-20) are used in some naval ships. Controllable pitch propellers give a ship excellent maneuverability and allow the propellers to develop maximum thrust at any given engine rpm. Ships with controllable pitch propellers require no reversing gear since the direction of the propeller thrust can be changed without a change in the direction of rotation. For high horsepower gas turbine powered ships, controllable pitch propellers are the only means available at this time for providing reverse thrust to the ship.

Controllable pitch propellers may be controlled from the bridge or from the engineroom through a hollow propulsion line shaft to the propeller hub. Hydraulic or mechanical controls are used to apply actuating force to the blades.

The hydraulic system is the most widely used means of providing the force required to change the pitch of a controllable pitch propeller. In this type of system a valve positioning mechanism actuates an oil control valve. The oil control valve permits hydraulic oil, under pressure, to be introduced to either side of a piston (which is connected to the propeller blade) and at the same time allows for the controlled discharge of hydraulic oil from the other side of the piston. This action repositions the piston and thus changes the pitch of the propeller blades.

Some controllable pitch propellers have mechanical means for providing the blade actuating force necessary to change the pitch of the blades. In these designs, a worm screw and crosshead nut are used instead of the hydraulic devices for transmitting the actuating force. The torque required for rotating the worm screw is supplied either by an electric motor or by the main propulsion plant through pneumatic brakes.



147.48

Figure 14-20.—A. Controllable pitch propeller for an LST. B. Hub of an MSO controllable pitch propeller.

In most installations propeller pitch and engine power are controlled through a single

320

lever. Movement of the lever causes both engine speed and pitch to change to suit the powering condition ordered. In emergencies, and in ships without single lever control, the propeller pitch can be changed independently of the power setting. Under this condition, overspeeding of the engine can result if the pitch is set too low.

Instructions regarding the limitations of engine speeds at different propeller pitches have been issued to all ships equipped with controllable pitch propellers. In addition, the special operating and maintenance instructions for these propellers should be consulted before any overhaul or repairs are undertaken.

CHAPTER 15

PUMPS AND VALVES

This chapter deals primarily with the routine maintenance of the pumps and valves which are commonly found in the various systems of internal-combustion engines.

PUMPS

An engine installation requires a number of pumps. Some of these pumps deliver fuel to the injection system or the carburetor; others circulate oil through the lubricating system; and still others circulate freshwater or seawater (or both) for engine cooling. Most of these pumps are attached to the engine and are driven by the engine crankshaft through gears, chains, or belts. However, some pumps are separate from the engine and are driven by electric motors.

Pump failure may cause failure of the plant or system to which the pump is providing service. For this reason, you must have a knowledge of the operating difficulties which may be encountered and know how to perform routine maintenance which will keep pumps in operation.

Before proceeding with this section, you should review the basic operating principles of pumps, discussed in *Fireman*, NAVEDTRA 10520-E. For additional information on pumps, you should consult *NAVSHIPS' Technical Manual* chapter 503 (9470) and the manufacturer's technical manual which is usually furnished with each pump.

ROTARY PUMPS

The operation of a positive-displacement rotary pump depends upon the principle that rotating screws, lobes, or gears trap the liquid in the suction side of the pump casing and force it to the discharge side. Positive-displacement rotary pumps have largely replaced reciprocating pumps for pumping viscous liquids in naval ships, as they have a greater capacity for their weight and occupy less space. (Positive displacement means that a definite quantity of liquid is pushed out on each revolution.)

Rotary pumps have very small clearances between rotating parts to minimize slippage (leakage) from the discharge side back to the suction side. With close clearances, these pumps must be operated at relatively low speeds to obtain reliable operation and maintain capacity over an extended period of time. (Some rotary pumps operate at 1,750 rpm or higher.) Operating the pumps at higher speeds will cause erosion and excessive wear, which will result in increased clearances.

Types of Rotary Pumps

There are several types of positive-displacement rotary pumps, including the simple gear type, herringbone gear type, helical gear type, lobe type, and screw type (low pitch and high pitch). The main features of gear and screw pumps will be discussed briefly in the following paragraphs.

SIMPLE GEAR PUMP.—The simple gear pump has two spur gears which mesh together; one is the driving gear, and the other is the driven gear. Clearances between the gear teeth and the casing and between the gear faces and the casing are only a few thousandths of an inch. When the gears turn, the teeth carry the liquid in the spaces between the teeth, at the suction side of the pump, towards the sides where the liquid is trapped between the tooth pockets and the casing and carried through to the discharge side of the pump. The liquid entering the discharge side cannot return to the suction side because the meshing teeth at the center force the liquid out of the tooth pockets. (The small lubricating oil pumps installed on many pumps and other auxiliary machinery are usually positive-displacement rotary pumps of the simple gear type.)

HERRINGBONE GEAR PUMP.–The herringbone gear pump is a modification of the simple gear pump. In the herringbone gear pump, one discharge phase begins before the previous discharge phase is entirely completed. This overlapping tends to provide a steadier discharge pressure than is obtained with the simple gear pump. In addition, the power transmission from the driving gear to the driven gear is smoother. There are no internal driving gears other than the pumping gears themselves. Power-driven pumps of this type are sometimes used for low-pressure fuel oil service, lubricating oil service, and diesel oil service.

HELICAL GEAR PUMP.–The helical gear pump (fig. 15-1) is still another modification of the simple gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump, and the discharge flow is, accordingly, even smoother. Since the discharge flow is smoother in the helical gear pump, the gears can be designed with fewer teeth–thus allowing increased capacity without sacrificing smoothness of flow.

In this type of pump, the pumping gears are driven by a set of timing and driving gears which

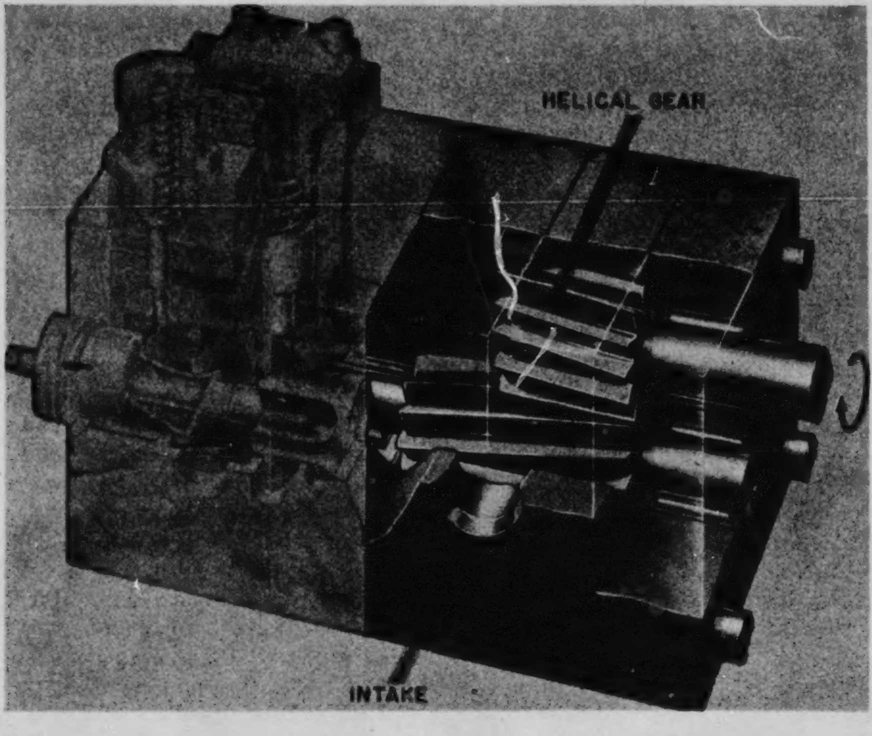


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Figure 15-1.–Helical gear pump.

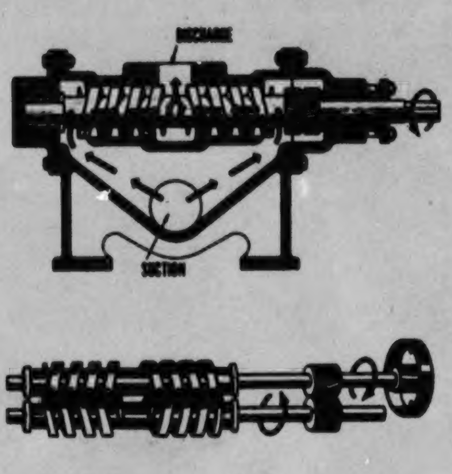
also function to maintain the required close tooth clearances while preventing actual metallic contact between the pumping gears. (Metallic contact between the teeth of the pumping gears would provide a tighter seal against slippage, but it would cause rapid wear of the teeth because foreign matter in the pumped liquid would be present on the contact surfaces.) Roller bearings at both ends of the gear shafts maintain proper alignment and decrease friction loss in the power transmission. Stuffing boxes are used to prevent leakage at the shafts. The helical gear pump is used to move nonviscous liquids and light oils at high speeds. In addition, it can be used to pump heavy, viscous material at a lower speed.

LOBE PUMP.–The lobe pump is another variation of the simple gear pump. (Modified versions of lobe pumps are used as superchargers on some engines and on vapor compression distilling plants.) The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. The rotors are driven by external spur gears on the rotor shafts.

SCREW PUMP.–There are many variations of screw pumps. The three main differences between these variations are the number of intermeshing screws, the pitch of the screw (low or high pitch), and the general direction of fluid flow (single or double flow).

Low Pitch, Double-Screw Pump.–The low pitch double-screw pump is illustrated in figure 15-2. The two pairs of screws, which intermesh with close clearances, are mounted on two parallel shafts. Each pair of screws has opposite threads with respect to the other pair. One shaft drives the other through a set of herringbone timing gears which maintain clearances between the screws as they rotate.

All clearances are small; there is no actual contact between the screws or between the screws and the casing. The liquid is trapped between the grooves of the screws and the casing, as indicated in the illustration. The meshing of the threads of the two screws forces the liquid along the grooves, toward the center (discharge side) of the pump. In the pump illustrated in figure 15-2, the liquid enters the thread grooves at both ends of the rotor or screws; thus the axial thrust of each side is balanced.



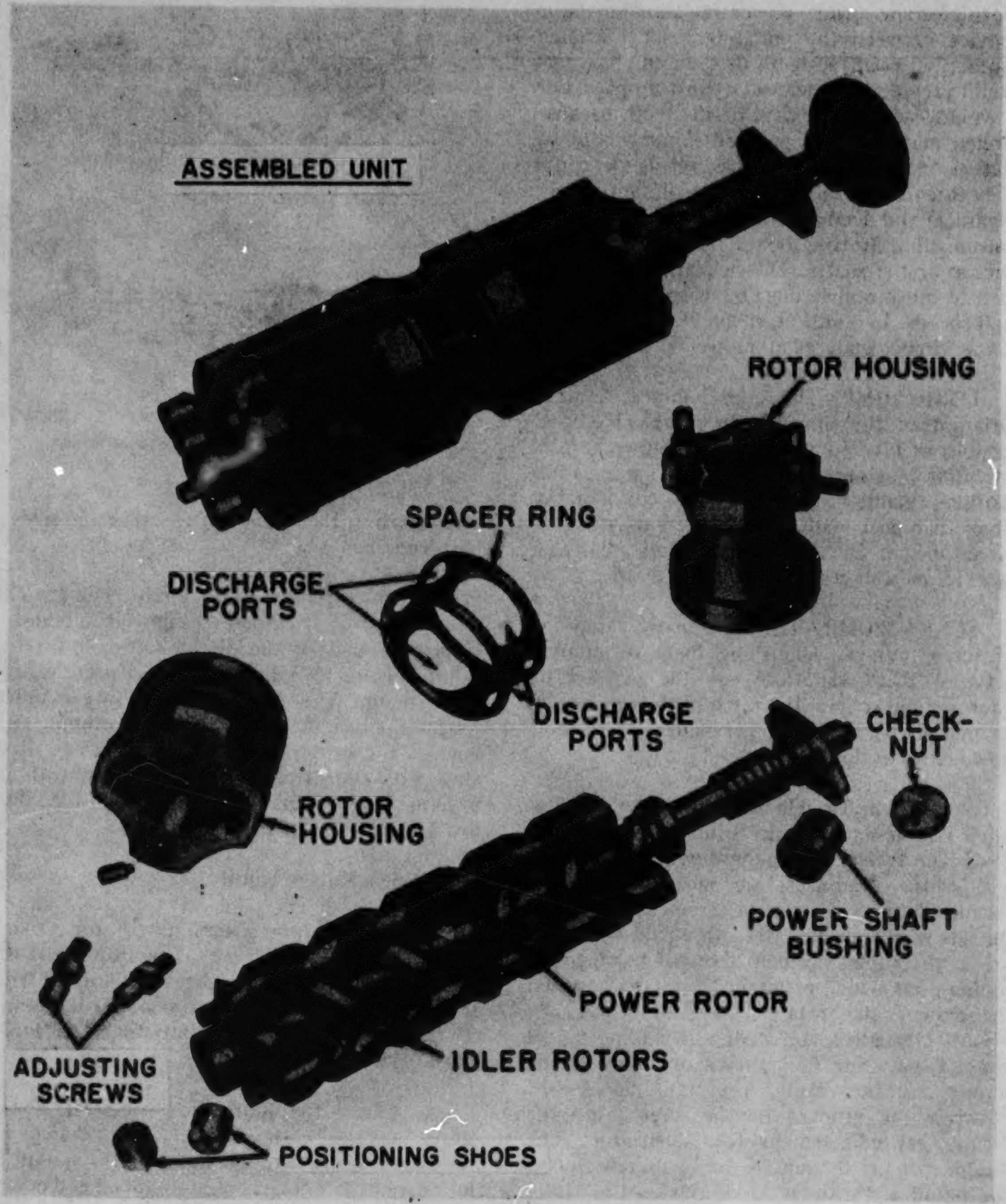
38.105X
Figure 15-2.–Low Pitch double-screw pump.

Triple-Screw, High Pitch Pump.–The operation of a triple-screw, high pitch pump is similar to that of the double-screw, low pitch pump. Figure 15-3 illustrates a triple-screw, high pitch pump. The pitch of the screws is much longer than in the low-pitch screw pump. This enables the center screw (power rotor) to drive the two outer (idler) rotors directly without external timing gears. The diameters of the idlers are less than that of the power rotor.

Operating a Rotary Pump

The operating instructions for the driving unit of rotary pumps vary. Therefore, read the posted instructions for the individual driving unit and pump before operating a specific pump. The following instructions apply for STARTING most rotary pumps:

1. Check the lubricating oil level in the sump tank or bearing housing. Fill oil cups or reservoir, if fitted. If the rotary pump is lubricated by a detached pump, open and adjust all delivery and return valves.
2. Open the valves on the pump packing gland seals, where such valves are fitted.


ASSEMBLED UNIT
ROTOR HOUSING
SPACER RING
DISCHARGE PORTS
DISCHARGE PORTS
CHECK-NUT
ROTOR HOUSING
POWER SHAFT BUSHING
POWER ROTOR
IDLER ROTORS
ADJUSTING SCREWS
POSITIONING SHOES

38.107

Figure 15-3.—Dismantled triple-screw high pitch pump.

3. Lift all relief and sentinel valves by hand.
4. Open the pump discharge valve.
5. Open the pump suction valve.
6. Start the driving unit—motor or engine.
7. Check the lubricating system to see that all bearings are supplied with oil and that the oil is at the correct pressure.
8. Check all gages to see that proper pressures are being developed.
9. Adjust the pump-shaft packing glands and gland-sealing needle valve, where fitted and where adjustment is needed.

The instructions for STOPPING and SECURING a pump are as follows:

1. Stop the driving unit. Be sure that the check valve of the pump discharge closes to prevent a backflow, through the pump being secured, from another pump which may be discharging into the same line.
2. Close the pump discharge stop valve.
3. Close the pump suction valve.
4. Close all supply and return valves—if the unit is lubricated by a detached pump or by a main lubricating oil system.

Operating Difficulties

When the pump speed is increased and (1) the pump fails to build up the required pressure or (2) it fails to discharge fluid when the discharge valve is open, proceed as follows:

1. Stop the unit.
2. See that all valves in the pump suction lines are open.
3. Check the packing of all suction and suction manifold valve stems to ensure that no air is being drawn into the suction piping.
4. Check the pump shaft packing for air leakage into the pump.
5. Check the spring case and the inlet and outlet connections of the discharge relief valve to ensure that no air is leaking into the pump suction.
6. Start the pump again. When it is up to the proper speed, read the suction gage to see if the pump is pulling a vacuum. If a low vacuum (5 or 6 inches of mercury, or less) is indicated, air is leaking into the pump suction. If no vacuum is shown on the suction gage, it is possible that the pump is not primed. (This should rarely occur after the pump casing has once been filled.) If the pump still does not build up pressure, close the discharge valve gradually, and note the pressure gage at the same time. If the pressure increases, an open discharge line is indicated. If the pressure does not increase, open the discharge valve and close the suction valve, noting if the vacuum builds up. If the pump is in good condition with close clearances, a vacuum ranging from 15 to 25 inches should build up on the suction line. If a high vacuum is indicated, an obstruction in the suction line is probably the reason the pump does not build up discharge pressure; or the suction strainer, if fitted, may be clogged.

If HEAVY POUNDING occurs when the pump is operating at high vacuum, considerable vaporization in the liquid end may be indicated. Pounding can be reduced by decreasing the pump speed.

Care and Repair

The instructions given in this chapter for the maintenance, repair, and operation of pumps are general for all makes and types. Manufacturer's technical manuals are furnished for all pump installations except some miscellaneous, small, motor driven pumps. These manuals contain detailed information concerning the specific pumps installed, and you should study them carefully before attempting to operate or service the pump.

WEARING PLATES AND LINES.—The clearances between pump rotors and casing wearing plates and cylinder liners should be maintained in accordance with the manufacturers' plans. On low-pressure, low-suction lift pumps such as lubricating oil, diesel oil supply, and tank drain pumps, the pressure drop across the clearance spaces does not generally exceed 50 psi. With these types of pumps, the clearance between parts may wear as much as 0.005 to 0.010 inch without appreciable effect upon the capacity of the individual pump. However, when the clearances

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are excessive, renewal of parts (wearing plates and liners) will be necessary. If a fuel oil tank drain pump, with the suction valve closed, will pull a vacuum of only 16 inches of mercury, renewal of parts may be necessary. In each instance the engineering officer will decide whether the amount of wear or increased clearance requires the renewal of parts.

BEARINGS.—If the pump bearings are worn excessively and it becomes necessary to renew the bearings, do not install the new bearings without spotting them in, or checking and fitting them to the designed clearance. The required oil clearance for bearings is usually given on the manufacturer's plans. If these plans are not available, refer to PMS.

TIMING GEARS.—Pumps fitted with timing gears must have the correct clearance between the two pumping rotors during operation. To accomplish this, the gears must be securely locked to the rotor shafts in their exact designed position. Be sure that there is no lost motion caused by the looseness of keys or pins holding the rotors in the shafts.

THRUST BEARINGS.—We must stress the importance of the proper setting of thrust bearings which hold the pumping elements centrally in the pumping casing. Examine thrust bearings quarterly and check the position of the rotors. When checking the rotor position, be sure to make enough allowance for expansion of the shaft from the cold condition to the hot running condition.

COUPLINGS.—When the driving unit is connected to the pump by a flexible coupling, remember that the coupling is intended to take care of slight misalignment. When misalignment is small, the coupling should operate satisfactorily without frequent renewal of (coupling) parts. However, if misalignment is excessive, the coupling parts take severe punishment, and the pins, bushings, and bearings must be replaced frequently.

Couplings with self-contained lubricant must be kept lubricated. A coupling will wear and eventually fail if its lubricant is lost. Therefore, you must observe the following precautions:

1. Inspect the flexible coupling monthly by removing the filler plug to be sure there is a sufficient supply of lubricant.
2. Whenever a coupling is dismantled, inspect the teeth to see that they are in good condition. When the coupling is reassembled, check the alignment of the driving unit and pump to prevent excessive coupling wear.

PUMP LUBRICATION.—Lack of proper lubrication is a primary cause of pump failures. Reciprocating engine-driven pumps are usually lubricated by either sight-feed drip cups or wick lubrication. See that oil cups are filled with oil and that an adequate supply is being fed to the bearings.

Water pump shafts are usually fitted with water flingers between the pump shaft stuffing-box gland and the bearing housing to prevent the entrance of water, from the pump glands, to the bearing housing.

Planned Maintenance

Periodic maintenance of pumps should be performed in accordance with the scheduled planned maintenance program.

Safety Precautions for Rotary Pumps

You must observe the following precautions in the operation of rotary pumps:

1. See that all relief valves are tested at the appropriate intervals. Ensure that relief valves function at the designated pressures.
2. Never attempt to jack over a pump by hand while the power is on.
3. Never operate a positive-displacement rotary pump with the discharge valve closed, unless the discharge is protected by a properly set and tested relief valve.
4. When working on any vertical, rotary, or centrifugal pump never rely on the pump coupling to support the weight of the pump rotor assembly. Support the pump rotor

assembly in slings or by other acceptable rigging methods.

CENTRIFUGAL PUMPS

Most modern diesel and gasoline engines use centrifugal pumps for circulating cooling water. There are many types of centrifugal pumps, but all operate on the same principle. The operation of centrifugal pumps depends upon centrifugal force (which imparts a high velocity to the liquid pumped) produced by the rotation of the impeller at high speed. The liquid is sucked in at the center, or EYE, of the impeller and discharged at the outer rim of the impeller.

By the time the liquid reaches the outer rim of the impeller, it has acquired considerable velocity. The liquid is then slowed down by being led through a volute or through a series of diffusing passages. As the velocity of the liquid decreases its pressure increases, or, in other words, some of the kinetic energy of the liquid is transformed into potential energy. In the terminology commonly used in the discussion of pumps, the velocity head of the liquid is partially converted to a pressure head.

Types of Centrifugal Pumps

There are two types of centrifugal pumps which you will probably encounter aboard ship: The volute pump and the diffuser pump.

In the VOLUTE PUMP, shown in figure 15-4 the impeller discharges into a volute—that is, a gradually widening channel in the pump casing. As the liquid passes through the volute and into the discharge nozzle, a considerable portion of its kinetic energy is converted into potential energy.

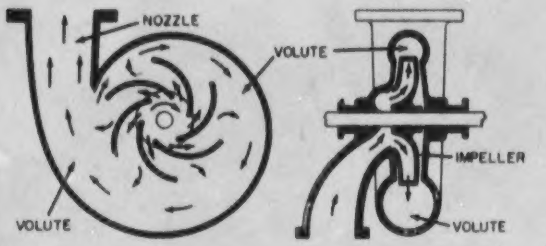

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Figure 15-4.—Simple volute pump.

In the DIFFUSER PUMP, shown in figure 15-5, the liquid leaving the impeller is first slowed down by the stationary vanes which surround the impeller. The liquid is forced through the gradually expanding passages of the diffuser ring before entering the volute. The diffuser vanes and the volute reduce the velocity of the liquid in the diffuser pump. In this type of pump there is an almost complete conversion of kinetic energy to potential energy.

Centrifugal pumps may be classified in several ways. For example, they may be either SINGLE STAGE or MULTISTAGE. A single-stage pump has only one impeller. A multistage pump has several impellers housed together in one casing; each impeller functions separately, discharging to the suction of the next stage impeller. Centrifugal pumps are also classified as HORIZONTAL or VERTICAL, depending upon the position of the pump shaft.

Construction of Centrifugal Pumps

The following information applies in general to most of the centrifugal pumps used with

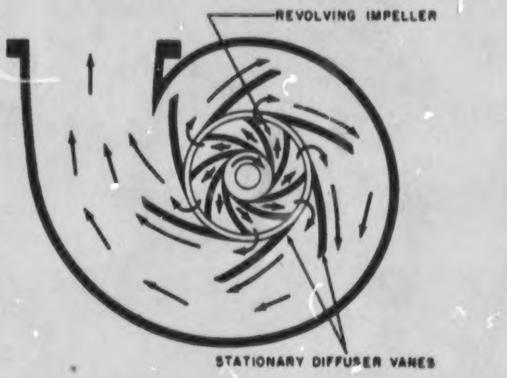

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Figure 15-5.—Diffuser pump.

diesel engines. Figure 15-6 shows the parts of one type of centrifugal pump.

The shaft is protected from excessive wear and corrosion by Monel or corrosion-resistant steel sleeves wherever the shaft comes in contact with the liquid being pumped or with the shaft packing. In many centrifugal pumps, the shaft is fitted with replaceable sleeves. The advantage of using sleeves is that they can be replaced more economically than the entire shaft.

The IMPELLERS used on centrifugal pumps may be classified as SINGLE SUCTION or DOUBLE SUCTION. The single-suction impeller allows liquid to enter the eye from one direction only; the double-suction type allows liquid to enter the eye from two directions. Impellers have side walls which extend from the eye to the outer edge of the vane tips; open impellers do not have these side walls. Most centrifugal pumps used by the Navy have closed impellers.

The impellers are carefully machined and balanced to reduce vibration and wear since they rotate at very high speed. A close radial clearance must be maintained between the outer hub of the impeller and that part of the pump casing in which the hub rotates, in order to minimize leakage from the discharge side of the pump casing to the suction side. (To prevent corrosion of pumps that handle seawater, the impellers and casings of these pumps are made of bronze or gun metal, and the shaft of Monel metal or stainless steel.)

Because of the close clearance and the high rotational speed of the impeller, the running surfaces of both the impeller hub and the casing at that point are subject to relatively rapid wear.

Centrifugal pumps are provided with replaceable wearing rings to eliminate the need for renewing an entire impeller and pump casing because of wear. One ring is attached to each

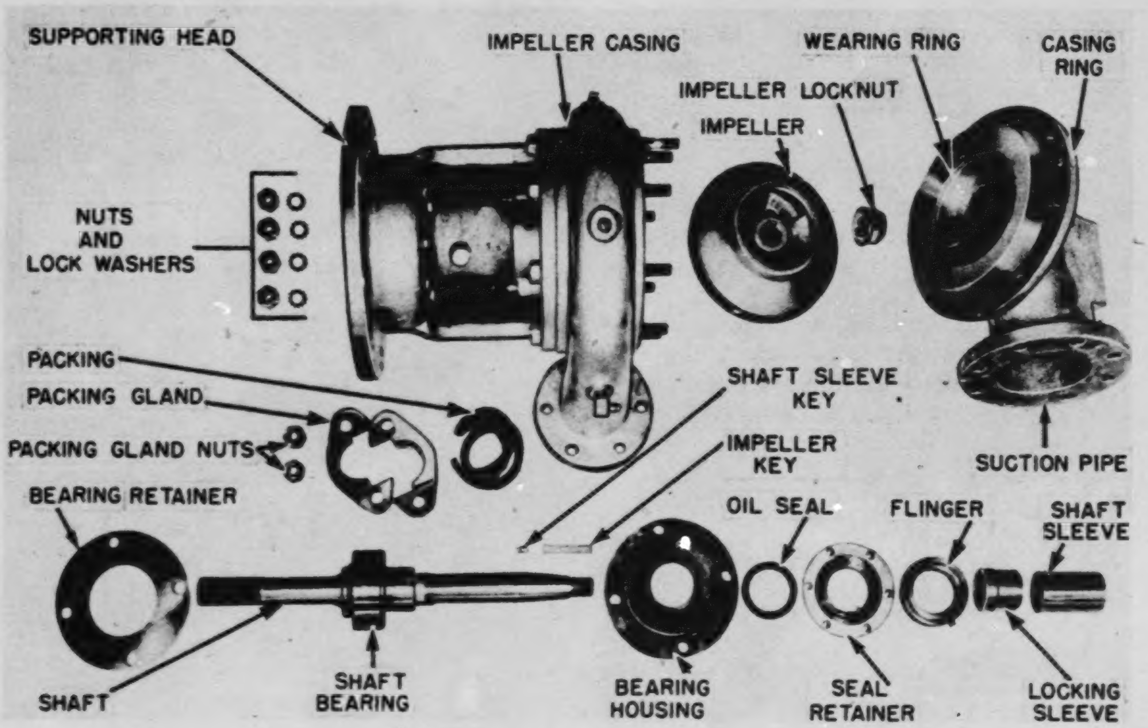
SUPPORTING HEAD
IMPELLER CASING
WEARING RING
CASING RING
IMPELLER LOCKNUT
IMPELLER
NUTS AND LOCK WASHERS
PACKING
PACKING GLAND
PACKING GLAND NUTS
SHAFT SLEEVE KEY
IMPELLER KEY
SUCTION PIPE
BEARING RETAINER
OIL SEAL
FLINGER
SHAFT SLEEVE
SHAFT
SHAFT BEARING
BEARING HOUSING
SEAL RETAINER
LOCKING SLEEVE

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Figure 15-6.—Exploded view of a centrifugal water pump.

outer hub of the impeller. This ring is called the IMPELLER WEARING RING. The other ring, which is stationary and attached to the casing, is called the CASING WEARING RING. Figure 15-7 illustrates an impeller and wearing rings.

Some small pumps with single-suction impellers have only a casing wearing ring and no impeller ring; in this type of pump, the casing wearing ring is fitted into the end plate.

RECIRCULATING LINES are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods. Seal piping is installed to cool the shaft and the packing, to lubricate the packing, and to seal the joint between the shaft and the packing against air leakage. A lantern ring spacer is inserted between the rings of the packing in the stuffing box. Seal piping leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft, between the shaft and the packing.

SHAFT and THRUST BEARINGS support the weight of the impeller and maintain the position of the rotor, both radially and axially. (Radial bearings may be sleeve or ball type. Thrust bearings may be ball type or pivoted segmental type.)

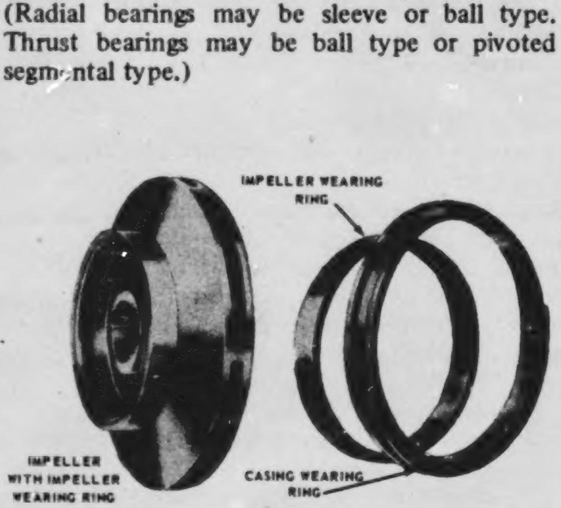

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Figure 15-7.—Impeller and wearing rings for a centrifugal pump.

The POWER END of a centrifugal pump may be driven by a steam turbine, by an electric motor, or by a diesel engine. Pumps used for continuous service are either turbine or motor driven. (Smaller pumps, such as those used for in-port or cruising operation, are generally motor driven.) Pumps used for emergency firemain services are generally diesel driven.

Care and Repair of Centrifugal Pumps

The tests, safety precautions, and maintenance factors for rotary pumps, outlined earlier in the chapter, are applicable in a general way to centrifugal pumps. However, some of the information which you must have in order to give proper care and maintenance to centrifugal pumps is given in this section. For additional information, as well as for specific information on any one pump, you should consult *NAVSHIPS' Technical Manual* and the appropriate manufacturer's technical manual.

STUFFING BOX PACKING.—Packing around the shafts of centrifugal pumps (fig. 15-8) may be either the stuffing box type or the labyrinth type, or both. Stuffing box packing should be renewed in accordance with t

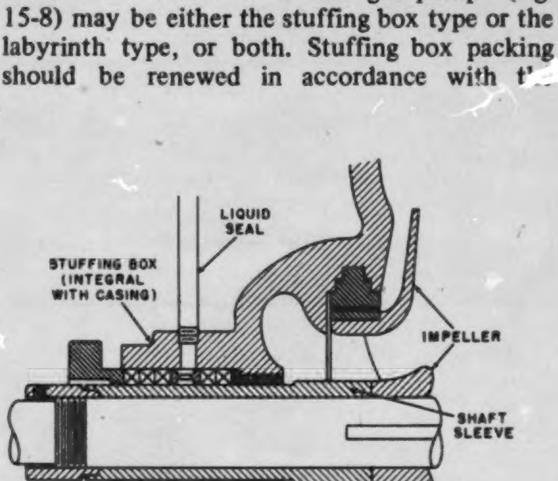

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Figure 15-8.—Stuffing box on a centrifugal pump.

Planned Maintenance System or whenever leakage becomes excessive. The packing should be installed in a uniform thickness all around the shaft sleeves. When installing new packing, pack the stuffing box loosely and set it up lightly on the packing gland. Then, with the pump in operation, tighten the gland in small steps, with several hours between tightenings, to compress the packing gradually. This procedure will prevent excessive heating and scoring of the shaft or shaft sleeves. A flow of from 40 to 60 drops per minute out of a normal packed-type stuffing box is required to provide lubrication and to dissipate generated heat.

Renew the labyrinth packing around worn bushings (bushing wear is due to wearing of the bearings) when the bearings are replaced. Examine the water supply to the packing seals frequently to ensure that it is not obstructed by the packing.

ROTARY SEALS.–In some pump installations, stuffing box packing is impractical since there must be a certain amount of leak-off for lubrication purposes. It could be rather dangerous to have leaking fluids such as distillate fuels or gasoline. Also many gallons of water could be lost from a freshwater system. In many installations, packing is being replaced by a mechanical seal.

When the seal requires replacement or when there are signs of abnormal wear or damage to the running surfaces, make a thorough inspection to find the cause. It is very important to find and correct the trouble, or the failure will recur. Seal failure is often caused by dirt on the running surfaces, worn bearings, or bent shafts.

Whenever the seal must be replaced, the complete assembly should be replaced in accordance with the manufacturers' instructions. Always be sure the shaft is free of dirt or lint. Then, carefully unwrap the seal, being careful not to touch the bearing surface with your fingers, rinse the seal in an approved cleaning solvent, and allow it to air dry. (NEVER wipe dry.) If a new seal assembly is not available, you may be able to repair the existing seal by lapping the mating surfaces.

LANTERN RINGS, SLEEVES, AND FLINGERS.–When packing a stuffing box fitted with a LANTERN RING (fig. 15-8), be sure to replace the packing beyond the lantern ring at the bottom of the stuffing box. In addition, see that the sealing water to the lantern ring is not blanked off by the packing.

SLEEVES fitted at the packing on the pump shafts must always be tight. These sleeves are usually made secure by shrinking or keying them to the shaft. Be sure that water does not leak between the shaft and shaft sleeves. If the shaft or sleeves are roughened or grooved, turn or grind them to give a smooth surface. If the surface is very rough, the sleeves should be renewed.

WATER FLINGERS.–Water flingers are fitted on shafts, outboard of stuffing box glands, to prevent water from following along the shaft and entering the bearing housings. The flingers must be tightly fitted. If the flingers are fitted on the shaft sleeves, rather than on the shaft, be sure that no water is allowed to leak under the sleeves. If leakage does occur, fit fiber washers between the ends of the sleeves and the shaft shoulders, and fill all clearances between the shaft and the sleeve with tallow.

WEARING RINGS, IMPELLER, AND CASING.–The clearances between the impeller and the casing wearing rings, as shown on the manufacturer's plans or the Maintenance Requirement Card, should be maintained. When clearances exceed the specified figures, the wearing rings must be replaced. This job can be done by the ship's force, but it requires the complete disassembly of the pump. If you must undertake this job, follow the manufacturer's instructions carefully; improper fitting of the rings or incorrect reassembly of the pump can result in serious damage.

SHAFT ALIGNMENT.–When installing or assembling pumps driven by electrical motors, steam turbines, or diesel engines, you must be sure that the unit is aligned properly. Misalignment may cause serious operating troubles later. It is absolutely necessary to have the rotating shafts of the driver and driven units in proper alignment as determined by the coupling.

Check the shaft alignment of a pump frequently or whenever the pump is opened up or whenever there is noticeable vibration. If the shafts are out of line or inclined at an angle to each other, the unit must be realigned to prevent shaft breakage and renewal of bearings, pump casing wearing rings, and throat bushings. Whenever practicable, check the alignment with all piping in place and with the adjacent tanks and piping filled.

Some driving units are connected to the pump by a FLEXIBLE COUPLING. Remember that flexible couplings are intended to take care of only slight misalignment. Misalignment should never exceed the amount specified by the pump manufacturer. If the misalignment is excessive, the coupling parts are subjected to severe punishment, necessitating frequent renewal of pins, bushings, and bearings.

When the driving unit is connected, or coupled, to the pump by a FLANGE COUPLING, the shafting must be frequently realigned. Each pump shaft must be kept in proper alignment with the shaft of the driving unit. Misalignments are indicated by such things as abnormal temperatures, abnormal noises, and worn bearings or bushings.

Wedges, or shims, are sometimes placed under the bases of both the driven and driving units (fig. 15-9A) for ease in alignment when the machinery is installed. Jacking screws may also be used to level the units. When the pump or driving unit, or both, have to be shifted sidewise to align the couplings, side brackets are welded in convenient spots on the foundation, and large setscrews are used to shift the units sidewise or endwise. When the wedges or other packings have been adjusted so that the outside diameters and faces of the coupling flanges run true as they are manually revolved, the chocks are fastened, the units are securely bolted to the foundation, and the coupling flanges are bolted together.

These ALIGNMENTS MUST BE CHECKED from time to time, and misalignments must be promptly corrected. In general practice there are

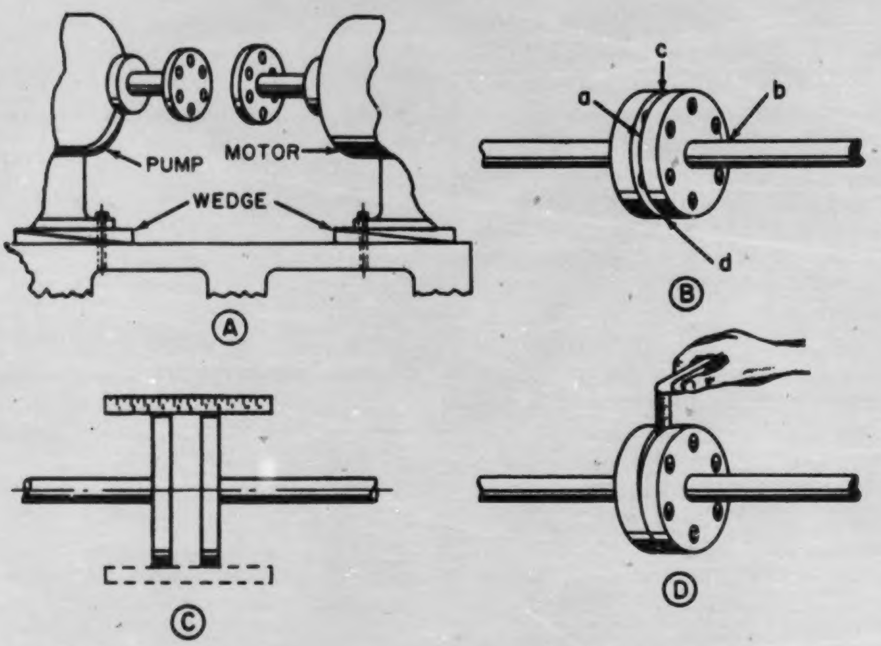

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Figure 15-9.—Coupling alignment.

three methods employed for checking the alignments:

1. Use a 6-inch scale
2. Use a thickness gage
3. Use a dial indicator

Some types of installations, of course, call for special methods of handling.

When USING A 6-INCH SCALE TO CHECK alignments, check the distance between the faces of the coupling flanges at 90° intervals. Find the distances between the faces at point a, point b (on the opposite side), point c, and point d (opposite point c) (fig.-15-9B). This will indicate whether the coupling faces are parallel with each other. If they are not parallel, adjust the driving unit or the pump, or both, with shims until the couplings check true. While measuring the distances, you must keep the outside diameters of the coupling flanges in line. To do this, place the scale across the two flanges as shown in figure 15-9C. If the flanges do not line up, raise or lower one of the units with shims. Then, if necessary, shift them sidewise, using the jacks welded on the foundation. The scale should be used (as shown in fig. 15-9C) at intervals of 90°, as was done in checking between the flange faces (fig. 15-9B).

The procedure for using a thickness gage to check alignments is similar to that for a scale. When the outside diameters of the coupling flanges are not the same, use a scale on the surface of the larger flange, then use "feelers" between the surface of the smaller flange and the edge of the scale. When the space is narrow, check the distance between the coupling flanges with a thickness gage (as shown in fig. 15-9D). Wider spaces are checked with a piece of square key-stock and a thickness gage. Revolve the couplings one at a time, and check at 90° intervals. If the faces are not true, the shaft has been sprung. Many times the shafts must be removed and sent to the ship's machine shop for reworking.

When USING A DIAL INDICATOR to check alignments, clamp the indicator to one coupling flange, then revolve the coupling with the point of the dial indicator on the shaft of the opposite coupling flange. If no variation is shown on the indicator, the coupling is running true. When the coupling with an indicator clamped to it is revolved while the opposite coupling remains still, the degree to which the coupling centers are out of line will be shown. To adjust the centers, loosen bolts at the unit bases and recheck the alignment. When alignment is true, secure the dowel at the unit bases, and insert and fasten the coupling bolts. Use dial indicators whenever possible when aligning a coupling.

Major Troubles and Repairs

A list of the principal troubles that may occur with centrifugal pumps, together with their causes, is given in figure 15-10.

If the pump fails to build up pressure when the discharge valve is opened and the pump speed is increased, proceed as follows:

1. Secure the pump.
2. Prime the pump to expel all the air through the air cocks on the pump casing.
3. Open all valves on the pump suction line.
4. Start the pump again. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller may be broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump, try to find the source of the trouble, and correct it, if possible.

The parts of a centrifugal pump that most frequently need repair or replacement are:

1. CASING WEARING RINGS AND IMPELLER WEARING RINGS: Since the purpose of these rings is to keep the internal bypassing of the liquid to a minimum, the clearances should be checked and restored, when worn beyond allowable limits, whenever the pump casing is opened up, and at least once each year.

2. SHAFT SLEEVES: There is a common tendency for operating personnel to take up too hard on the packing in an attempt to prevent

PUMP TROUBLES	CAUSES
Failure to Deliver Water	**Pump not primed; insufficient speed; impeller plugged; wrong direction of rotation (this may occur after motor overhaul)**
Short in Capacity	**Air leaks in stuffing boxes; insufficient speed; insufficient suction head for hot water; suction strainers fouled; impellers damaged and casing packing defective**
Pressure Low	**Insufficient speed; air leak; incorrect discharge valves open in manifold (this may allow the pump to discharge into an open line, causing the pump to operate at other than the design point); mechanical defects: (same as for Short in Capacity)**
Pump Loses Water After Starting	**Leaky suction line; water seal plugged; suction lift too high (often caused by fouling of the strainer after the pump is started); air or gases in water**
Pump Overloads Driver	**Speed too high; liquid of different specific gravity and viscosity too high; rubbing caused by foreign matter in the pump, and between the casing rings and the impeller; mechanical defects: rotating element binds, shaft bent, and worn bearings**
Pump Vibrates	**Misalignment; poor foundation; impeller partially clogged, causing unbalance; mechanical defects: (same as for Pump Overloads Driver)**

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Figure 15-10.—Centrifugal pump troubles and causes.

stuffing box leakage. This causes scoring of the shaft sleeves. Whenever the pump is opened, the sleeves should be examined and if slightly scored, they should be smoothed up; if they are badly scored, they should be replaced.

3. BEARINGS: Worn sleeve bearings cause the rotor to drop which, in turn, causes excessive wear of the casing wearing ring and the impeller ring. When a bearing is worn excessively, it should be replaced as soon as possible, in accordance with the manufacturer's instruction manual.

Whenever a replaceable precision type bearing is disassembled, it should be inspected carefully for ridges, scores, and wear. The bearing lining should be firmly anchored to the shell. If the bearing is scored, or worn beyond the manufacturer's recommended tolerance, it should be replaced.

Journals should be kept free from rust and should be kept smooth at all times. To remove rust spots, ridges, and sharp edges of scores, the journals should be lapped with an oilstone or with an oilstone powder.

4. BUSHINGS: Whenever a pump is disassembled, bushing clearances should be measured. Bearing wear will probably cause bushing wear, and the bushings should be renewed if the bearings are restored to their original readings.

VARIABLE STROKE PUMPS

Variable stroke pumps are used largely on electrohydraulic steering gear, elevators, and cranes. Although they are generally classified as rotary pumps, they actually operate on somewhat the same principle as a single-acting reciprocating pump. A rotary motion is imparted to the pump by a constant-speed electric motor, but the actual pumping is done by a set of pistons reciprocating inside a set of cylinders. The way in which these pumps translate rotary motion into reciprocating motion is explained and illustrated in *Fireman*, NAVEDTRA 10520-E.

There are two general types of variable stroke pumps commonly used aboard naval ships. In the axial-piston type, the pistons are arranged parallel to each other and to the pump shaft; in the radial-piston type, the pistons are arranged radially from the shaft.

Axial-Piston Variable Stroke Pump

An axial-piston variable stroke pump usually has either seven or nine single-acting pistons which are evenly spaced around a cylinder barrel. (Cylinder barrel, as used here, actually refers to a barrel-shaped block which holds all the cylinders.) The piston rods make a ball-and-socket connection with a socket ring. The socket ring rides on a thrust bearing carried by a casting known as the tilting box (tilting block).

When the tilting block is at a right angle to the shaft, the pump is rotating but the pistons do not reciprocate; therefore, no pumping takes place. However, when the block is tilted (away from the right angle), the pistons reciprocate and the liquid is pumped.

When the variable stroke axial-piston pump is used as a part of the power unit of such equipment as electrohydraulic anchor windlasses, cranes, winches, and steering engines, the tilting block is arranged so that it may be tilted in either direction. Thus, the pump may be used to transmit power hydraulically to pistons or rams, or it may be used to drive a hydraulic motor. In the latter case, the pump, which is driven by a constant-speed electric motor, is connected by pipes or tubing to a hydraulic motor. This motor is similar in design to a hydraulic pump except that most motors have the tilting block mounted in a fixed position. When the tilting block is fixed, the motor shaft turns in the direction, and at a speed directly related to the direction and angle of tilt, of the tilting block in the variable stroke pump.

Radial-Piston Variable Stroke Pump

The pumping action of a radial-piston variable stroke pump (fig. 15-11) is similar to the axial-piston type just described. However, the component parts are arranged differently. In a radial-piston pump, the cylinders are arranged radially in a cylinder body which rotates around a nonrotating central cylindrical valve or pintle. As the cylinder body revolves, each cylinder contacts either an intake port or an outlet port in the central cylindrical valve. Plungers or pistons, which extend outward from each cylinder, butt against a slipper ring on the inside of a rotating float ring or rotor.

The floating ring is so constructed that it can be shifted off center from the pump shaft. When it is in the neutral position, the pistons do not reciprocate and the pump does not operate, even though the electric motor is still causing the pump to rotate. If the floating ring is forced off center to one side, the pistons reciprocate and the pump operates. If the floating ring is forced off center to the other side of the pump shaft, the pump also operates, but the direction of flow and the amount of flow are both determined by the position of the cylinder body relative to the position of the floating ring.

JET PUMPS

Unlike other pumps, a jet pump has no moving parts. A simple jet pump, illustrated in figure 15-12, consists of a jet supply line, a jet or nozzle, a suction line, a suction chamber, a diffuser, and a discharge line.

In a jet-type pump, pumping action is created by passing a fluid (water, steam, or air) through a nozzle, at a high pressure and velocity through a chamber that has suction and discharge openings.

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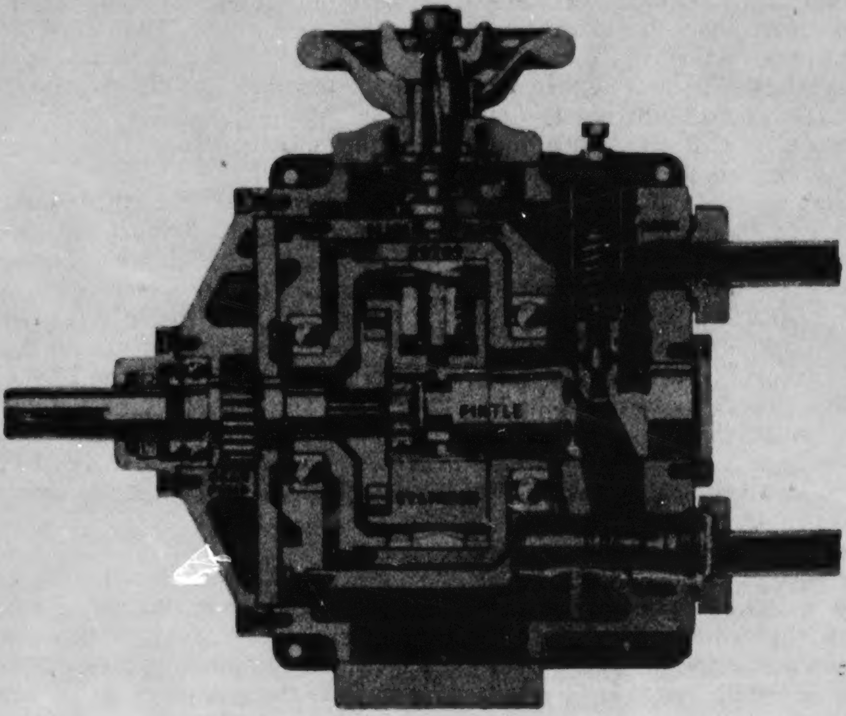

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Figure 15-11.–Radial-piston variable stroke pump.

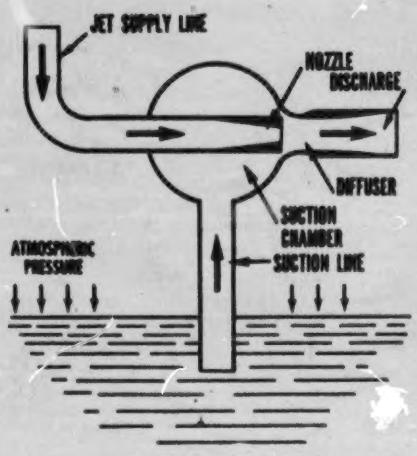
JET SUPPLY LINE
NOZZLE
DISCHARGE
DIFFUSER
SUCTION
CHAMBER
SUCTION LINE
ATMOSPHERIC
PRESSURE

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Figure 15-12.–Simple jet-type pump.

The principles of jet pump operation are as follows: Upon starting up, the rapidly moving jet fluid pushes on and gives sufficient motion to the air (or whatever substance may be in the suction chamber) to carry it out through the discharge line. Displacing of the air from the suction chamber creates a partial vacuum, within the suction chamber, causing fluid to flow through the suction line. The fluid entering the chamber from the suction line is picked up by the high velocity fluid, thus providing continuous pumping action.

The suction lift and discharge pressure of a simple jet-type pump are not so great as the lift and pressure of other types of pumps. However, a special class of jet pumps, such as two-stage air ejectors, is capable of creating greater suction lift than most mechanically operated pumps.

Because of their simplicity, jet pumps generally require very little maintenance. Since there are no moving parts, only the nozzles will show wear. The erosion action will cause the nozzles to become enlarged; in this case they are generally renewed. Occasionally the nozzles are removed; the strainers, if fitted, are cleaned; and a special reamer is inserted in the nozzles to clean out any rust or scale that may have accumulated.

VALVES

In the various systems of an internal-combustion engine, valves of many types are used to regulate the quantity of liquid flowing to the various components of the systems. All valves used in engine systems may be grouped in two general classifications: manually operated valves and automatic valves.

Manually operated valves include all valves that are adjusted by hand. Automatic valves include check valves, thermostatic valves, and pressure-regulating valves. Most of these valves have been introduced and illustrated in *Fireman*, NAVEDTRA 10520-E. Thermostatic valves were discussed in chapter 8 of this manual. The valves considered in this chapter are primarily of the manual type. Some of the troubles that may be encountered with valves and information on general maintenance are presented in this section.

GLOBE VALVES

The repair of globe valves (other than routine renewal of packing) is generally limited to refinishing the seat and disk surfaces. When this work is being done, there are certain precautions that should be observed.

When refinishing the valve face and seat, do not remove any more material than necessary. Valves that do not have replaceable valve seats can be refinished only a limited number of times.

Before doing any repair to the seat and disk of a globe valve, check to be sure that the valve disk is secured rigidly to, and is square on, the valve stem. Also, check to be sure that the stem is straight. If the stem is not straight, carefully inspect the valve disk for evidence of wear, for cuts on the seating area, and for improper fit of the disk to the seat. If the disk and the seat appear to be in good condition, spot-in to find out whether they actually are in good condition.

Spotting-in Globe Valves

Spotting-in is the method used to visually determine whether the seat and the disk make good contact with each other. To spot-in a valve seat, first apply a thin even coating of prussian blue over the entire machined face surface of the disk. Then, insert the disk into the valve and rotate it a quarter turn, using a light downward pressure. The prussian blue will adhere to the valve seat at those points where the disk makes contact. Figure 15-13 shows a correct seat when it is spotted-in; it also shows various kinds of imperfect seats.

After you have noted the condition of the seat surface, wipe all the prussian blue off the disk face surface. Apply a thin, even coat of prussian blue to the contact face of the seat, and again place the disk on the valve seat and rotate the disk a quarter of a turn. Examine the resulting blue ring on the valve disk. The ring should be unbroken and of uniform width. If the blue ring is broken in any way, the disk is not making a proper fit.

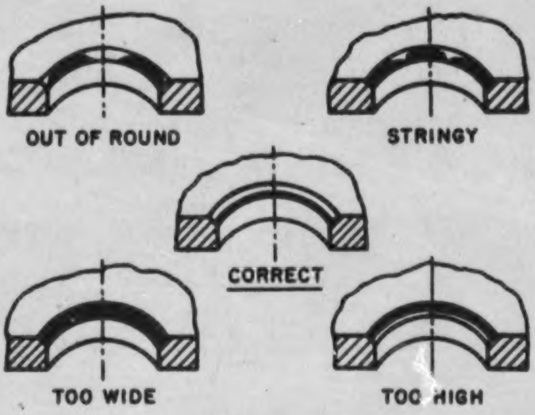

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Figure 15-13.—Examples of spotted-in valve seats.

Grinding-in Globe Valves

Grinding-in is the manual process used to remove small irregularities from the contact surfaces of the seat and the disk of a valve. Do not confuse grinding-in with refacing processes in which lathes, valve reseating machines, or power grinders are used to recondition the seating surfaces.

To grind-in a valve, first apply a small amount of grinding compound to the face of the disk. Then insert the disk into the valve and rotate the disk back and forth about a quarter of a turn; shift the disk-seat relation from time to time so that the disk will be moved gradually, in increments, through several rotations. During the grinding process, the grinding compound will gradually be displaced from between the seat and disk surfaces; therefore, you must stop every minute or so to replenish the compound. When you do this, you should wipe both the seat and the disk clean before applying the new compound to the disk face.

When it appears that the irregularities have been removed, spot-in the disk to the seat, in the manner previously described.

Grinding is also used to follow up all machining work on valve seats or disks. When the valve seat and disk are first spotted-in after they have been machined, the seat contact will be very narrow and will be located close to the bore. Grinding-in, using finer and finer compounds as the work progresses, causes the seat contact to become broader. The contact area should be a perfect ring, covering approximately one-third of the seating surface.

Be careful that you do not overgrind a valve seat or disk. Overgrinding tends to produce a groove in the seating surface of the disk; it also tends to round off the straight, angular surface of the disk. Machining is the only process by which overgrinding can be corrected.

Lapping Globe Valves

When a valve seat contains irregularities that are slightly larger than can be satisfactorily removed by grinding-in, the irregularities can be removed by lapping. A cast-iron lapping tool (lap), of exactly the same size and shape as the valve disk, is used to true the valve-seat surface. Two lapping tools are shown in figure 15-14.

The most important points to remember while using the lapping tool are:

1. Do not bear heavily on the handle of the lap.
2. Do not bear sideways on the handle of the lap.
3. Change the relationship between the lap and the valve seat so that the lap will gradually and slowly rotate around the entire seat circle.
4. Keep a check on the working surface of the lap. If a groove develops, have the lap refaced.
5. Always use clean compound for lapping.
6. Replace the compound often.
7. Spread the compound evenly and lightly.
8. Do not lap more than is necessary to produce a smooth, even seat.
9. Always use a fine grinding compound to finish the lapping job.
10. Upon completion of the lapping job, spot-in, grind-in the disk to the seat, and remove any traces of grinding or lapping compound.

Use only approved abrasive compounds for reconditioning valve seats and disks. There are four grades of compounds for lapping and grinding valve disks and seats. A coarse-grade compound is used when extensive corrosion or

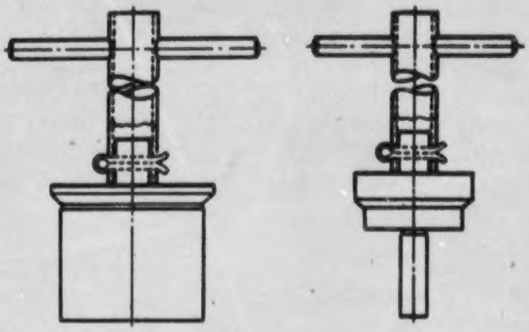

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Figure 15-14.—Lapping tools.

deep cuts and scratches are found on the disks and seats. A compound of medium grade is used to follow up the coarse grade; it may also be used to start the reconditioning process on valves which are not severely damaged. A fine-grade compound should be used when the reconditioning process nears completion. A microscopic fine grade is used for finish lapping, and for all grinding-in.

Refacing Globe Valves

Badly scored valve seats may be refaced in a lathe, with a power grinder, or with a valve reseating machine. The lathe, rather than the reseating machine, should be used for refacing all valve disks and all hard surfaced valve seats. Work that must be done on a lathe or with a power grinder should be turned over to shop personnel. The discussion here applies only to refacing valve seats with a reseating machine of the type shown in figure 15-15.

To reface a valve seat with a reseating machine, attach the correct facing cutter to the machine. With a fine file, remove high spots on the surface of the flange on which the chuck jaws must fit. (Note: A valve reseating machine can be used ONLY with a valve that has the inside of the bonnet flange bored true with the valve seat; if this condition does not exist, the valve must be reseated in a lathe and the inside flange must be bored true.)

Before placing the chuck in the valve opening, open the jaws of the chuck wide enough to rest on the flange of the opening. Now tighten the jaws lightly so that the chuck securely grips the sides of the valve opening. Tap the chuck down with a wooden mallet until the jaws rest firmly and squarely on the flange; then tighten the jaws.

Adjust and lock the machine spindle in the cutting position and start the cutting by turning slowly on the crank. Feed the cutter slowly so that very light cuts are taken. After some experience, you will learn by "the feel" whether the tool is cutting evenly all around. Remove the chuck and determine if enough metal has been removed from the face of the seat.

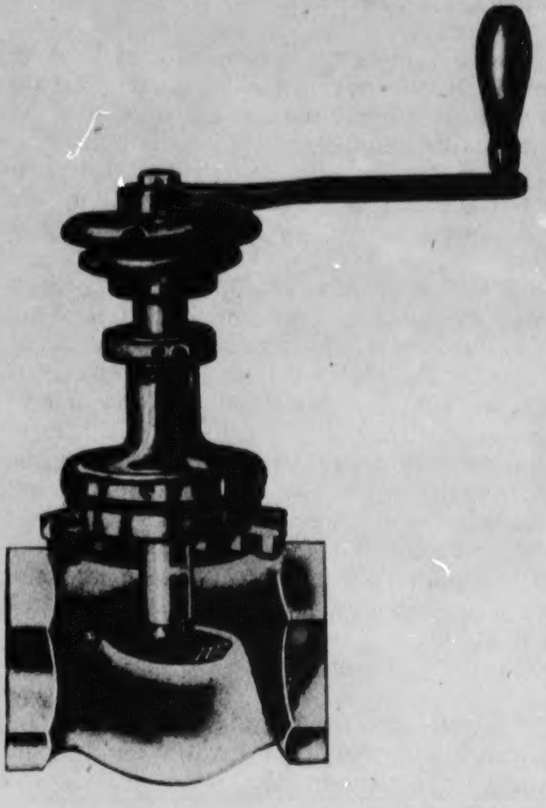

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Figure 15-15.—Valve reseating machine.

Be sure the seat is perfect. Then remove the cutter and face off the top part of the seat with a flat cutter. Dress the seat down to the proper dimensions, as follows:

WIDTH OF SEAT	SIZE OF VALVE
1/16 inch	1/4 to 1 inch
3/32 inch	1 1/4 to 2 inches
1/8 inch	2 1/2 to 4 inches
3/16 inch	4 1/2 to 6 inches

After the refacing, grind in the seat and disk. Spot-in as necessary to check the work. A rough method of spotting-in that you may use is to place pencil marks on the bearing surface of the seat or disk; then place the disk on the seat and rotate the disk about a quarter of a turn. If the pencil marks on the seating rub off, the seating is considered satisfactory.

Repacking Valve Stuffing Boxes

If the stem of a globe is in good condition, stuffing-box leaks can usually be stopped by tightening up on the gland. If this does not stop the leakage, repack the stuffing box. The gland must not be set up on or packed so tightly that the stem binds. If the leak persists, a bent or scored valve stem may be the cause of the trouble.

NAVSEA has a four-digit number symbol system for identifying each kind and type of packing considered necessary in the naval service. The first digit indicates the class of service with respect to fixed and moving joints. The second digit indicates the material of which the packing or gasket is primarily composed—asbestos, vegetable fiber, rubber, metal, etc. The third and fourth digits indicate the different types or forms of packing made from the material. The NAVSEA Mechanical Standard Drawing B 153 shows the symbol index for all types and kinds of shipboard packings and gaskets necessary in the naval service, and the recommended application.

Most ships have a packing and gasket chart made up specially for each ship. The shipboard chart shows the symbol numbers and the sizes of packing and the gaskets required in the ship's piping system, machinery, and hull fittings.

To install packing does not require great skill, but a mechanically correct job demands care. When installing packing in moving parts, be sure that:

1. The proper material is used. Consult the packing chart.
2. The rod or stem is not bent, scored, or rusty.
3. The packing gland is in alignment with the rod or stem.
4. The packing gland is not cocked.
5. The old packing has been removed.
6. The threads on the gland studs are not burred so as to prevent setting up of the gland nuts.

Cut the end of the packing rings square, and leave about a 1/16-inch space between the ends to allow for elongation when the gland is tightened. Place the packing in the stuffing box so that the joints will be staggered. Never fill the stuffing box to the extent that the gland cannot enter. Set the gland nuts up evenly and permit some leakage while the packing is adjusting itself to the stem. Never jam the packing glands tight with a wrench.

GATE VALVES

The manner in which a gate valve is used has a great deal to do with the service life of the valve. Gate valves should always be used either wide open or fully closed. They should not be used in a partially opened position. When a gate valve is partly open, the gate is not held securely; therefore, it swings back and forth with the pulsation of the flow. As the gate swings, it strikes the valve body and the finished surfaces, nicking and scoring them. When these surfaces are imperfect, the valve gate cannot seat accurately and seal off the flow. A gate valve should never be installed in any position where a throttling or flow-regulating valve is required; for such service a globe valve should be used.

Lapping is the best method for correcting gate-valve defects such as light pitting or scoring and imperfect seat contact. The lapping process is the same for gate valves as it is for globe valves, except that the lap is turned by a handle which extends through the end of the valve body. The lapping tool, without its handle, is inserted into the valve in such a manner that it covers one of the seat rings. Then, the handle is attached to the lap and the lapping is begun. The wedge gate can be lapped to a true surface, using the same lap that is used on the seat rings. CAUTION: DO NOT use the gate as a lap.

No more material should be removed than is necessary. It is possible to resurface a gate valve only a limited number of times. By removing too much material each time, the total number of times the surfaces can be renewed will be decreased, and the overall life of the valve will thereby be shortened.

On larger gate valves, when the seat rings become so deteriorated that they cannot be repaired by lapping, the seat rings can be

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removed from the valve body and replaced with new ones.

It is not advisable to attempt to repair a gate valve without removing it from the piping system. Removing the valve simplifies the repair job and gives more assurance that a good job will be performed.

Leakage around the stem of a gate valve is caused by troubles similar to those encountered in leaking globe valves. The procedure for stopping leakage around the valve stem is the same for both types of valves.

PLUG-COCK VALVES

Manually operated valves of the plug-cock type are sometimes used in the lines of the engine cooling system. A plug-type valve has a rotating plug which is drilled for the passage of the fluid. Rotation of the plug changes the position of the drilled passages with respect to the ports of the valve. In this manner, the rate (and, in three-way proportioning valves, the direction) of flow of the coolant is adjusted.

A hard lubricant in stick form is used to effectively seal and lubricate the rotating plug. Proper lubricating ensures tightness, maximum life, and ease of operation. Improper lubrication may cause the valve to stick or to leak and may cause excessive wear of the rotating plug. Excessive lubrication should be avoided as it may cause grease to be deposited in the cooling-system components.

Instructions relative to the proper lubrication of plug-cock valves must be followed strictly, if valve trouble is to be avoided. Many times, it is necessary only to lubricate the valve to eliminate leakage or sticking of the plug. However, if the valve has not been properly lubricated for a long time, it may be necessary to replace valve parts that have been damaged by lack of lubricant.

To lubricate the valve, remove the lubricant setscrew and insert a stick of lubricant. (The type of lubricant to be used depends upon the fluid that the valve is handling.) The lubricant is forced into the plug-cock valve by the lubricant setscrew until the lubricant is forced out around the neck or the stem of the valve. A check valve within the lubricant passage allows the plug-cock valve to be lubricated under pressure. When a plug-cock valve is being lubricated, the valve must be either wide open or completely closed. If this precaution is not taken, the lubricant will be forced into the water stream and will not lubricate the valve.

CHECK VALVES

Check valves are used to prevent the backflow of fluid in a line. A typical check valve is actuated by a light spring that seats the valve when the flow ceases.

Leaks are the principal trouble encountered with check valves. Leakage is caused by a pitted disk or valve seat. Such pitting usually results when abrasives are caught between the disk and the seat.

When a check valve requires maintenance because of pitting, the work required will depend upon the type of disk in the valve. When a leaking check valve has a ball-type disk, it will be necessary to replace the ball and to grind the seat. When a defective valve has a flat or conical disk, it will usually be possible to repair the damaged surfaces by grinding the disk to its seat, with a fine grinding compound.

When installing or replacing check valves, remember that fluid will flow through them in only one direction. Be sure that they are installed correctly.

PRESSURE-REGULATING VALVES

Pressure-regulating valves are required in a lubricating oil system to maintain an even lubricating oil pressure as the engine speed changes. Since lubricating oil pumps are of the positive-displacement type, it is essential that excess oil has some means of escape; otherwise, extremely high pressures will develop in the lines and at the bearings. Defective pressure-regulating valves are indicated by low and erratic lubricating oil pressures which are most noticeable when the lubricating oil temperature is high. There are many other factors, however, that will cause the same symptoms; these include a clogged filter or cooler; a worn oil pump, loose bearings, a low oil level, high oil temperatures, oil dilution, and oil leaks.

Most pressure-regulating valve failures are due to wear in the valves. However, a valve may

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Figure 15-16.–Butterfly valve.

fail to function properly because of a loose locknut, a scored seating surface, the binding of moving parts, or other defects.

If the adjusting-screw locknut becomes loose, the adjusting screw will back off, decreasing the tension in the spring and the load on the valve. Scored and pitted valves and valve seats will cause poor pressure control. When the valve seat and the disk become badly pitted, the operation of the valve will often be irregular; sometimes it will maintain normal pressure, and at other times it will allow the pressure to fall below the required level. If the assembly becomes gummed, due to either the oil or foreign particles in the oil, the disk will stick in the open position and will offer no restriction to the amount of oil bypassed. This effect is more noticeable at lower speeds. When a pressure-regulating valve fails to function properly because of wear, the valve should be replaced.

BUTTERFLY VALVES

The butterfly valve, illustrated in figure 15-16, has some advantages in certain applications over the gate and globe valves. The butterfly valve is light in weight; it takes up less space than a gate valve or a globe valve; it is easy to overhaul; and it is relatively quick acting.

Although the design and construction of butterfly valves may vary somewhat, a butterfly-type disk and some means of sealing are common to all valves of this type.

The butterfly valve described in this chapter consists of a body, a resilient seat, a butterfly-type disk, a stem, packing, a notched positioning plate, and a handle. This valve provides a positive shutoff; it may be used as a throttling valve set in any position from full open to full closed where the pressure drop across the valve does not exceed 40 psi. The replaceable resilient seat is held firmly in place by mechanical means; neither bonding nor cementing is necessary. It is not necessary to grind, lap, or do machine work to replace the valve seat, so overhaul of the valve is relatively simple. The resilient seat is under compression when it is mounted in the valve body, thus making a seal around the periphery of the disk and both upper and lower points where the stem passes through the seat. Packing is provided to form a positive seal around the stem in the event the seal formed by the seat becomes damaged. When closing the valve, you need to turn the handle only a quarter of a turn to rotate the disk 90°; the resilient seat exerts positive pressure against the disk, ensuring a tight shutoff.

Butterfly valves are designed to meet a variety of applications. The shipboard systems in which these valves are now being used include freshwater, seawater, JP-5 fuel, Navy special fuel oil, diesel oil, and lubricating oil.

CHAPTER 16

COMPRESSED AIR SYSTEMS

As an EN3 or EN2 you should have a thorough knowledge of air compressors, their construction, and care. You will find that compressed air serves many purposes aboard ship and that air outlets are installed in various suitable locations throughout the ship. The uses of compressed air include, but are not limited to, the operation of pneumatic tools and equipment, prairie-masker system, diesel engine starting and/or speed control, air deballasting, torpedo charging and ejecting, aircraft starting and cooling, and the operation of pneumatic boiler and propulsion control systems. Compressed air is supplied to the various systems by high-pressure, medium-pressure, or low-pressure air compressors, depending on the needs of the ship. Reducing valves may be used to reduce high-pressure air to a lower pressure for a specific use.

AIR COMPRESSORS

The air compressor is the heart of any compressed air system. The compressor takes in atmospheric air, compresses it to the pressure desired, and "pumps" the air into supply lines or into storage for later use.

There are a number of variations in the design, construction, and method of compression of air compressors. The construction and principles of operation of some of the most common types of air compressors, used in Navy ships, will be discussed in this chapter.

COMPRESSOR CLASSIFICATIONS

Air compressors are classified in various ways. A compressor may be duplex single-stage or multistage and horizontal, angle, or vertical, as shown in figure 16-1.

In a duplex compressor (fig. 16-1D) the two pistons travel together (parallel). In other words, both pistons (compression elements) are either discharging or taking a suction at the same time.

A compressor may be designed so that either ONLY one stage of compression takes place within one compressing element or so that MORE than one stage takes place within one compressing element. In a single-stage compressor the compression of the air, from suction pressure to final discharge pressure, is completed in a single compression element, i.e., a single cylinder. In a multistage compressor the air is compressed in two or more compression elements to reach final discharge pressure.

In addition, a compressor may be either single-acting (compression takes place in only one stroke per revolution) or double-acting (compression takes place on both strokes per revolution, meaning that compression is taking place on both sides of the piston and that each end of the cylinder is fitted with suction and discharge valves).

In general, compressors are classified according to capacity (high or low) type of compressing element, the source of driving power, the method by which the driving unit is connected to the compressor (belt-driven, direct-connected, etc), the pressure developed, and whether the air delivered is oil free or nonoil free.

Types of Compressing Elements

Shipboard air compressors may be centrifugal, rotary, or reciprocating. The

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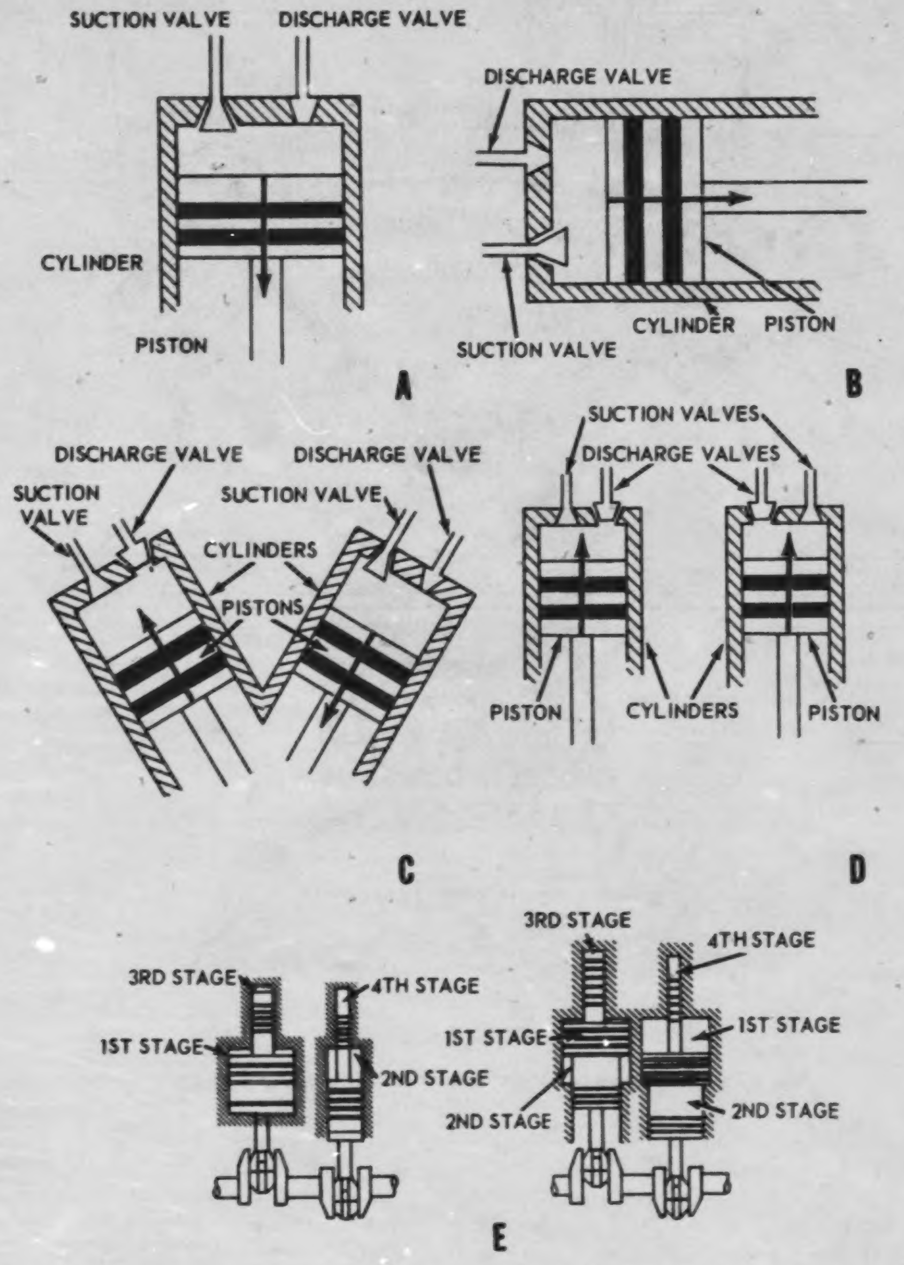
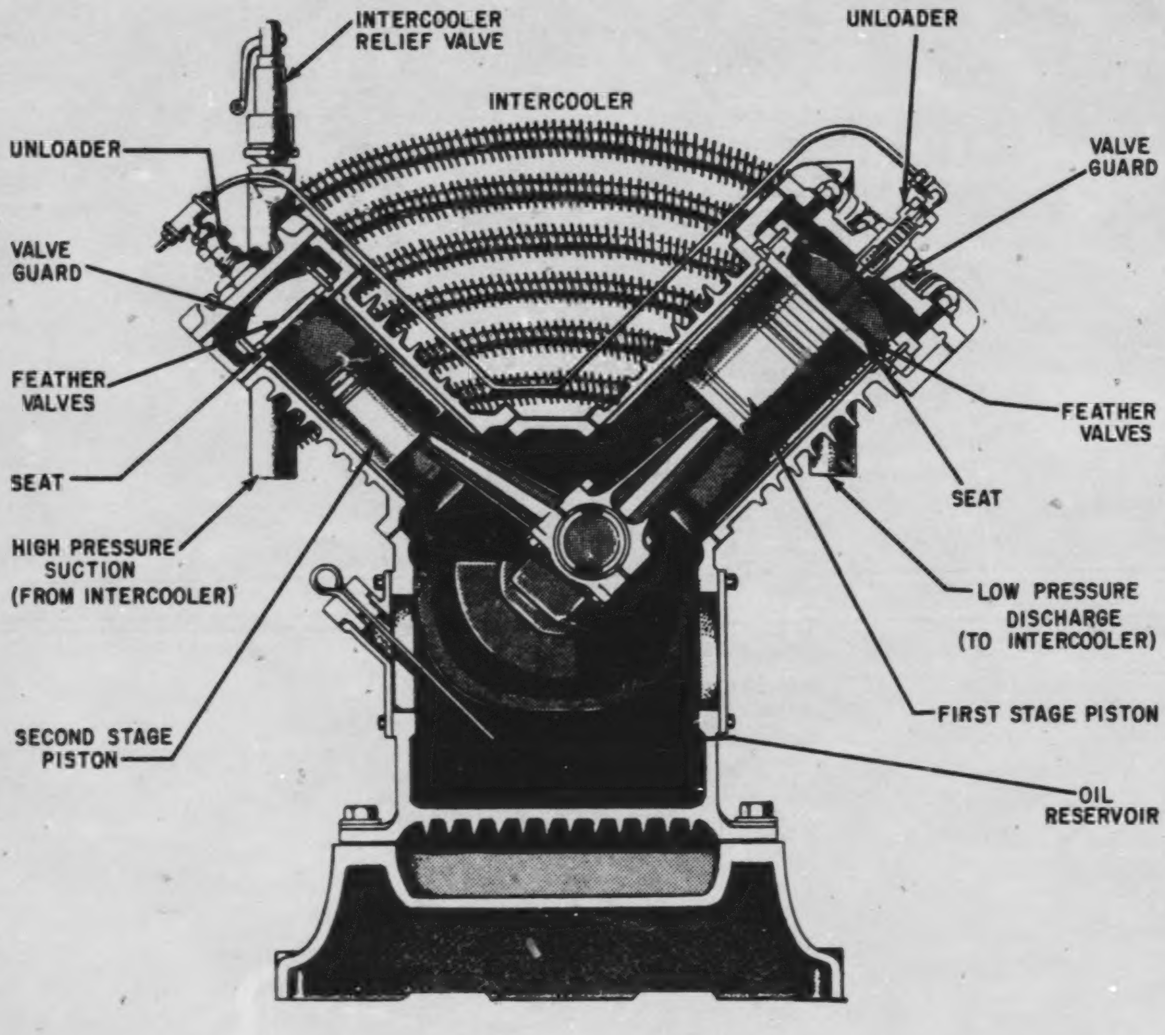

SUCTION VALVE
DISCHARGE VALVE
CYLINDER
PISTON
A
DISCHARGE VALVE
SUCTION VALVE
CYLINDER
PISTON
B
DISCHARGE VALVE
DISCHARGE VALVE
SUCTION VALVE
SUCTION VALVE
CYLINDERS
PISTONS
C
SUCTION VALVES
DISCHARGE VALVES
PISTON
CYLINDERS
PISTON
D
3RD STAGE
4TH STAGE
1ST STAGE
2ND STAGE
3RD STAGE
4TH STAGE
1ST STAGE
1ST STAGE
2ND STAGE
2ND STAGE
E

47.151

Figure 16-1.–Types of air compressors: A. Vertical. B. Horizontal. C. Angle. D. Duplex. E. Multistage.


INTERCOOLER RELIEF VALVE
UNLOADER
INTERCOOLER
UNLOADER
VALVE GUARD
VALVE GUARD
FEATHER VALVES
SEAT
HIGH PRESSURE SUCTION (FROM INTERCOOLER)
SECOND STAGE PISTON
FEATHER VALVES
SEAT
LOW PRESSURE DISCHARGE (TO INTERCOOLER)
FIRST STAGE PISTON
OIL RESERVOIR

47.152

Figure 16-2.—A simple two-stage reciprocating low-pressure air compressor.

reciprocating type is generally selected for capacities from 200-800 cubic feet per minute (cfm) and for pressures of 100 to 5,000 psi; the rotary lobe type for capacities up to 8,800 cfm and for pressures no more than 20 psi; and the centrifugal type for 800 cfm or greater capacities (up to 2,100 cfm in a single unit) and for up to 125 psi.

Most general-service-use air compressors aboard ship are "reciprocators" (fig. 16-2). In this type compressor the air is compressed in one or more cylinders, very much like the compression that takes place in an internal-combustion engine.

Sources of Power

Compressors are driven by electric motors or steam-turbines. Aboard ship, most low-pressure and high-pressure air compressors are driven by electric motors.

Drive Connections

The driving unit may be connected to the compressor by one of several methods. When the compressor and the driving unit are mounted on the same shaft, they are close-coupled. Close coupling is usually restricted to small capacity compressors that are driven by electric motors. However, the high-speed, single-stage, centrifugal, turbine-driven units serving prairie-masker systems in FF 1052 and similar ships are close-coupled. Flexible couplings are used to join the driving unit to the compressor when the speed of the compressor and the speed of the driving unit are the same. This is called a direct-coupled drive.

V-belt drives are commonly used with small, low-pressure, motor-driven compressors, and with some medium-pressure compressors. In a few installations, a rigid coupling is used between the compressor and the electric motor of a motor-driven compressor. In a steam-turbine drive, compressors are usually (not always) driven through reduction gears, or, in the case of centrifugal (high speed) compressors, through speed increasing gears.

Pressure Classification

In accordance with *NAVSHIPS' Technical Manual*, compressors are classified as low pressure, medium-pressure, or high-pressure. Low-pressure compressors have a discharge pressure of 150 psi or less. Medium-pressure compressors have a discharge pressure of 151 psi to 1,000 psi. Compressors that have a discharge pressure above 1,000 psi are classified as high-pressure.

Most low-pressure reciprocating air compressors are of the two-stage type with either a vertical "V" (fig. 16-2) or a vertical "W" (fig. 16-3) arrangement of cylinders. Two-stage, two-cylinder, V-type low-pressure compressors have one cylinder for the first (lower pressure) stage of compression and one cylinder for the second (higher pressure) stage of compression. Three-cylinder, W-type compressors have two cylinders for the first-stage of compression and one cylinder for the second stage. This arrangement is also shown in part A of figure 16-4. Notice that the pistons in the lower pressure stage (1) have a larger diameter than the piston in the higher pressure stage (2).

Medium-pressure air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons; this type of piston has more than one stage of compression during each stroke of the piston. (See fig. 16-4A.)

Most high-pressure compressors have motor-driven, liquid-cooled, four-stage, single-acting units with vertical cylinders. Example of the cylinder arrangements for high-pressure air compressors installed in Navy ships are illustrated in part B of figure 16-4. Small capacity high-pressure air systems may have three-stage compressors. Large capacity, high-pressure air systems may be equipped with four-, five-, or six-stage compressors.

OPERATING CYCLE OF RECIPROCATING AIR COMPRESSORS

Reciprocating air compressors are similar in design and operation. The following discussion relates to the operating cycle during one stage of compression in a single-stage, single-acting compressor.

The cycle of operation, or compression cycle, within an air compressor cylinder (shown in fig. 16-5) includes two strokes of the piston: a suction stroke and a compression stroke. The suction stroke begins when the piston moves away from top dead center (TDC). The air under pressure in the clearance space (above the piston) expands rapidly until the pressure falls below the pressure on the opposite side of the inlet valve. At this point, the difference in pressure causes the inlet valve to open, and air is admitted to the cylinder. Air continues to flow into the cylinder until the piston reaches bottom dead center (BDC).

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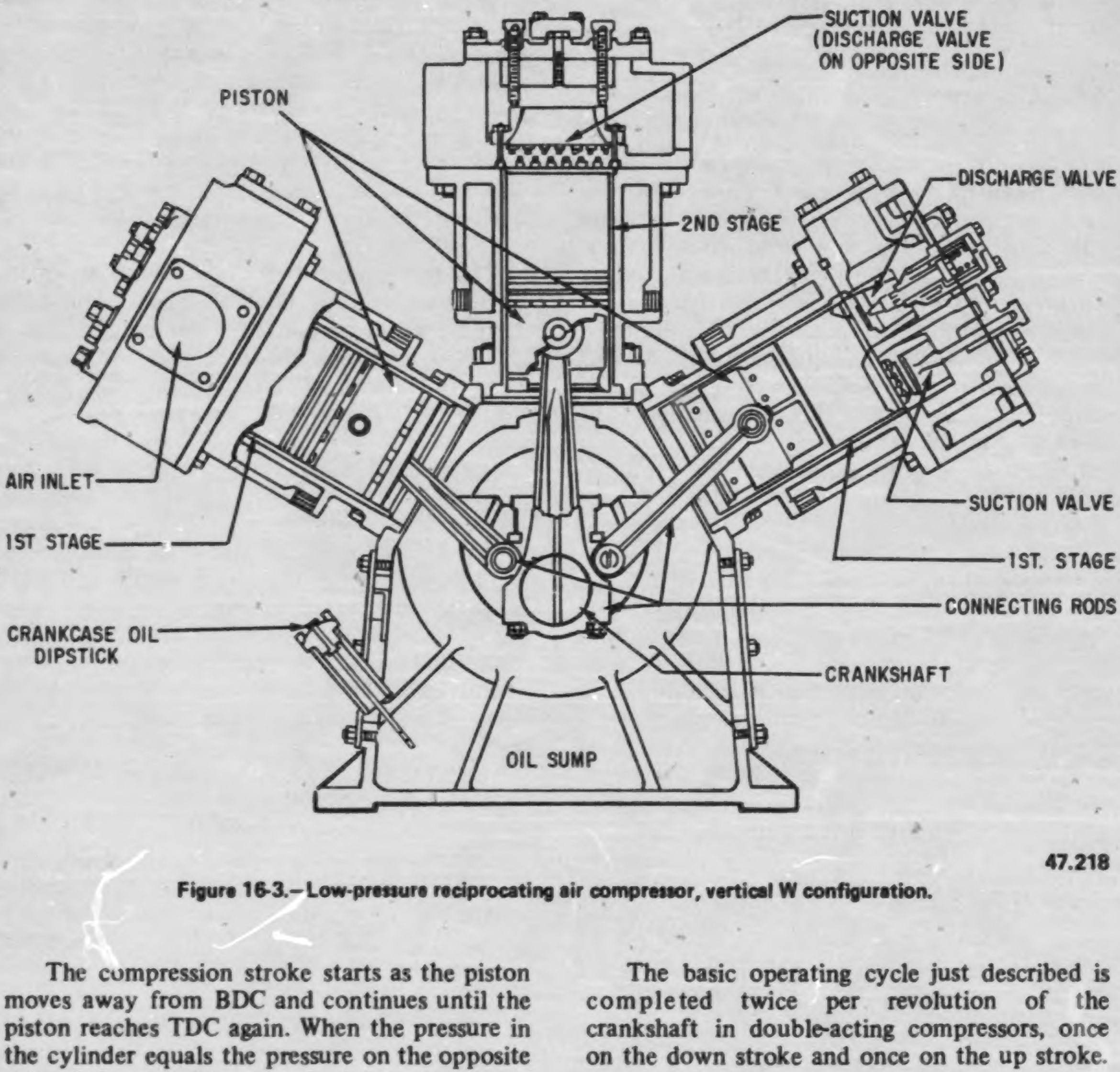
SUCTION VALVE (DISCHARGE VALVE ON OPPOSITE SIDE)
PISTON
DISCHARGE VALVE
2ND STAGE
AIR INLET
1ST STAGE
SUCTION VALVE
1ST. STAGE
CONNECTING RODS
CRANKCASE OIL DIPSTICK
CRANKSHAFT
OIL SUMP

47.218

Figure 16-3.—Low-pressure reciprocating air compressor, vertical W configuration.

The compression stroke starts as the piston moves away from BDC and continues until the piston reaches TDC again. When the pressure in the cylinder equals the pressure on the opposite side of the air inlet valve, the inlet valve closes. Air continues to be compressed as the piston moves toward TDC, until the pressure in the cylinder becomes great enough to force the discharge valve open against the discharge line pressure and the pressure of the valve springs. (The discharge valve opens shortly before the piston reaches TDC.) During the remainder of the compression stroke, the air which has been compressed in the cylinder is discharged at almost constant pressure through the open discharge valve.

The basic operating cycle just described is completed twice per revolution of the crankshaft in double-acting compressors, once on the down stroke and once on the up stroke.

COMPONENT PARTS OF RECIPROCATING AIR COMPRESSORS

Reciprocating air compressors consist of a system of connecting rods, crankshaft, and flywheel, which are used to transmit power developed by the driving unit to the pistons, as well as lubrication systems, cooling systems, control systems, and unloading systems.

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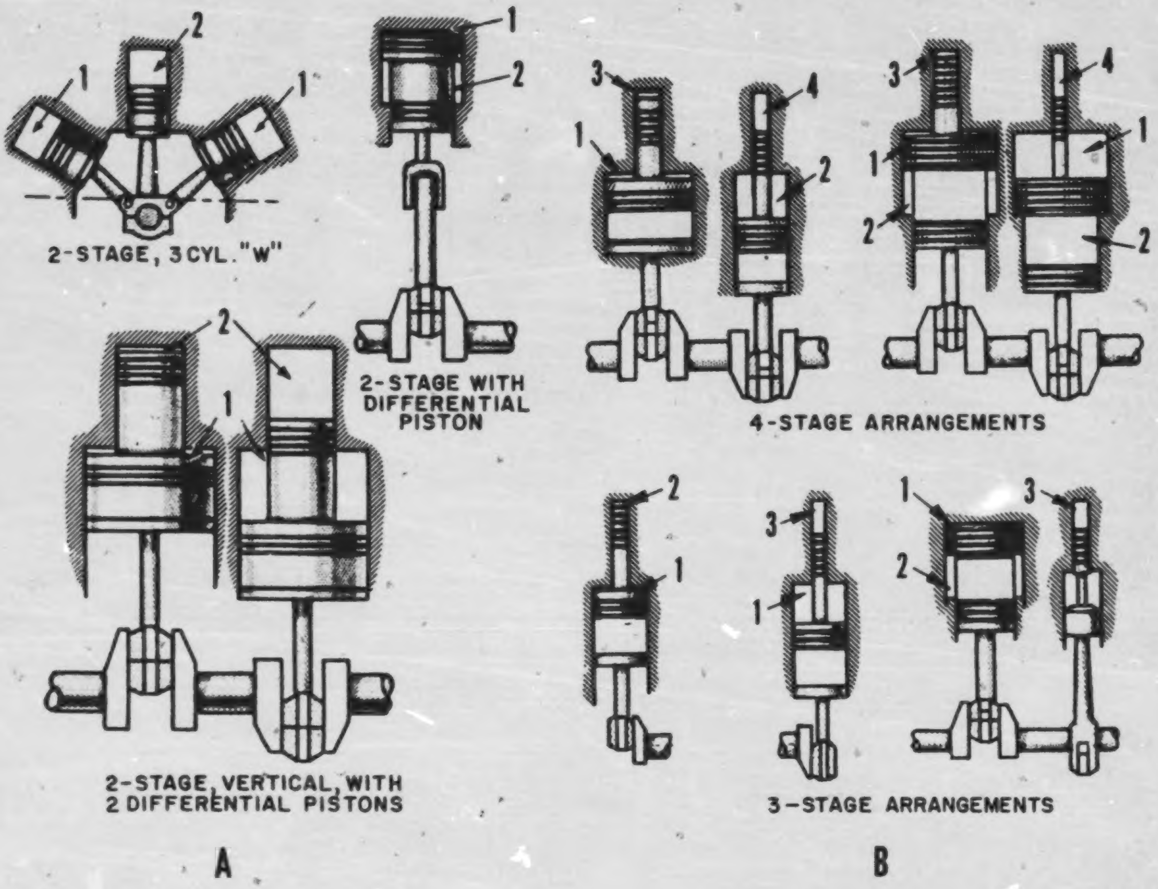

2-STAGE, 3 CYL. "W"
2-STAGE WITH DIFFERENTIAL PISTON
2-STAGE, VERTICAL, WITH 2 DIFFERENTIAL PISTONS
4-STAGE ARRANGEMENTS
3-STAGE ARRANGEMENTS
1
2
3
4
A
B

47.153

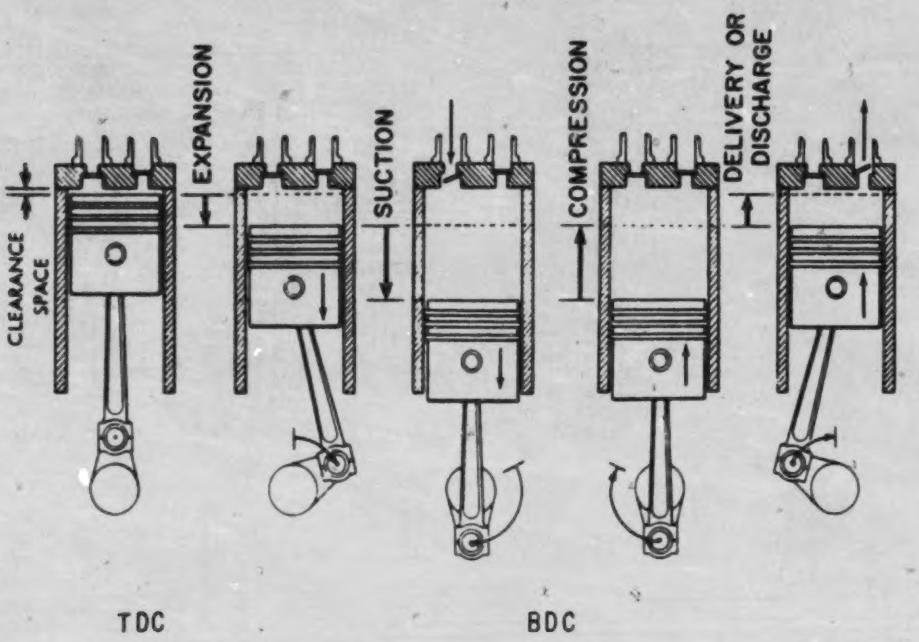
Figure 16-4.–Air compressor cylinder arrangements: A. Low- and medium-pressure compressors. B. High-pressure compressors.

Compressing Element

A compressing element of a reciprocating compressor consists of the cylinder, the piston, and the air valves.

VALVES.–The valves are made of special steel and come in a number of different types. The opening and closing of the valves is caused by the difference between (1) the pressure of the air in the cylinder and (2) the pressure of the external air on the intake valve or the pressure of the discharged air on the discharge valve.

Two types of valves commonly used in high-pressure air compressors are shown in figure 16-6. The strip, or feather, type valve shown in part A of the figure is used for the suction and discharge valves of the lower pressure stages, i.e., 1 and 2. The valve shown in the figure is a suction valve; the discharge valve assembly (not shown) is identical except that the positions of the valve seat and the guard are reversed. At rest, the thin strips lie flat against the seat, covering the slots and sealing any pressure applied to the guard side of the valve. In either a suction or discharge operation (depending on the valve service), as soon as pressure on the seat side of the valve exceeds the pressure on the guard side, the strips flex against the contoured recesses in the guard and permit air to pass around the



47.219

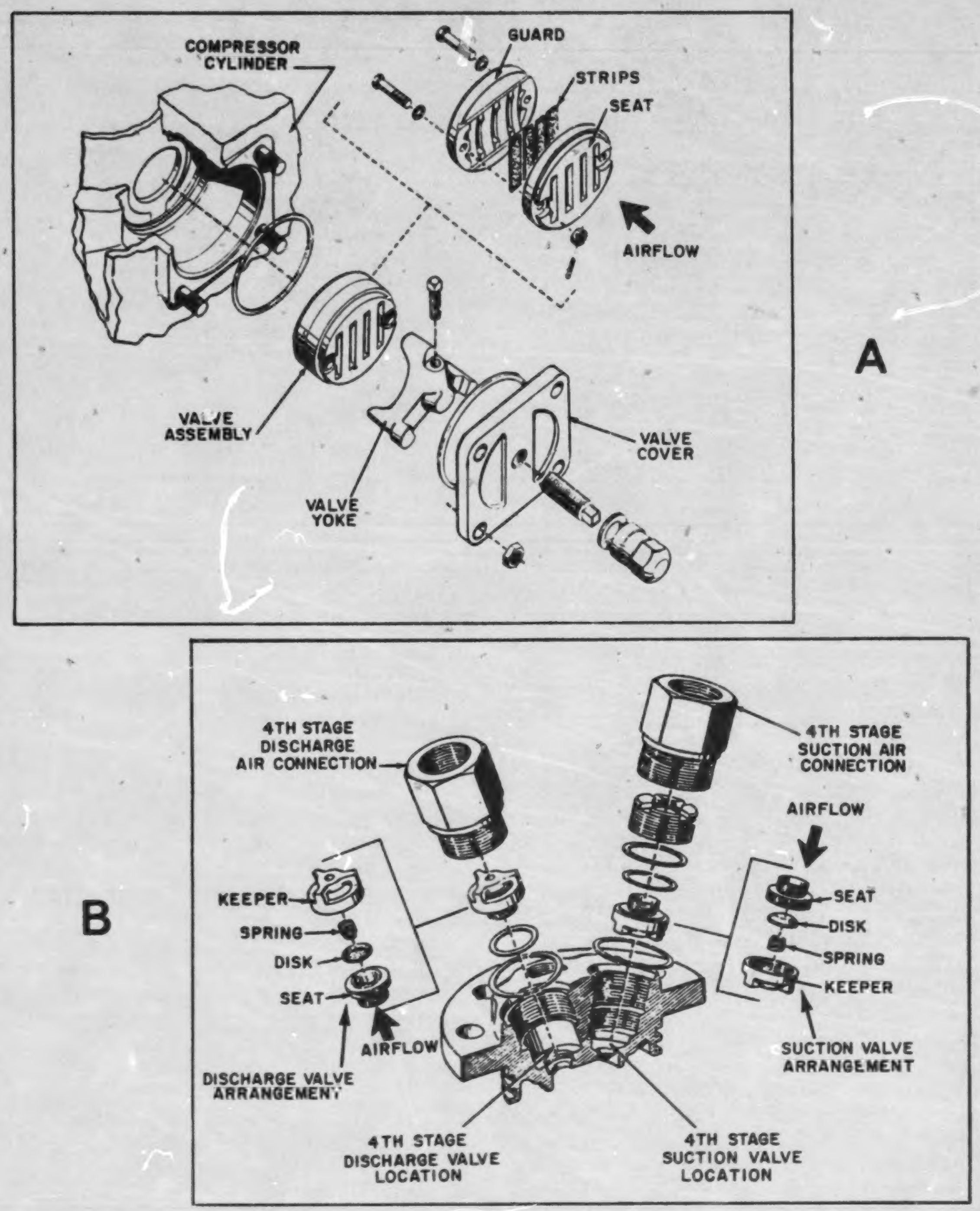
Figure 16-5.—The compression cycle.

edges of the strip and through the slots in the guard. As soon as the pressure equalizes or reverses, the strips unflex and return to their original position flat against the seat.

The disk-type valve in part B of figure 16-6 is used for the suction and discharge valves of the higher pressure stages, i.e., 3 and 4. The fourth stage assembly is shown. These valves are of the spring-loaded, dished-disk type. At rest, the disk is held against the seat by the spring and is sealed by pressure applied to the keeper side of the valve. In either a suction or discharge operation (depending on the valve service), as soon as the pressure on the seat side of the valve exceeds the pressure on the keeper side, the disk lifts against the stop in the keeper, compressing the spring, and permitting air to pass through the seat, around the disk and through the openings in the sides of the keeper. As soon as the pressure equalizes or reverses, the spring returns the disk to the seat.

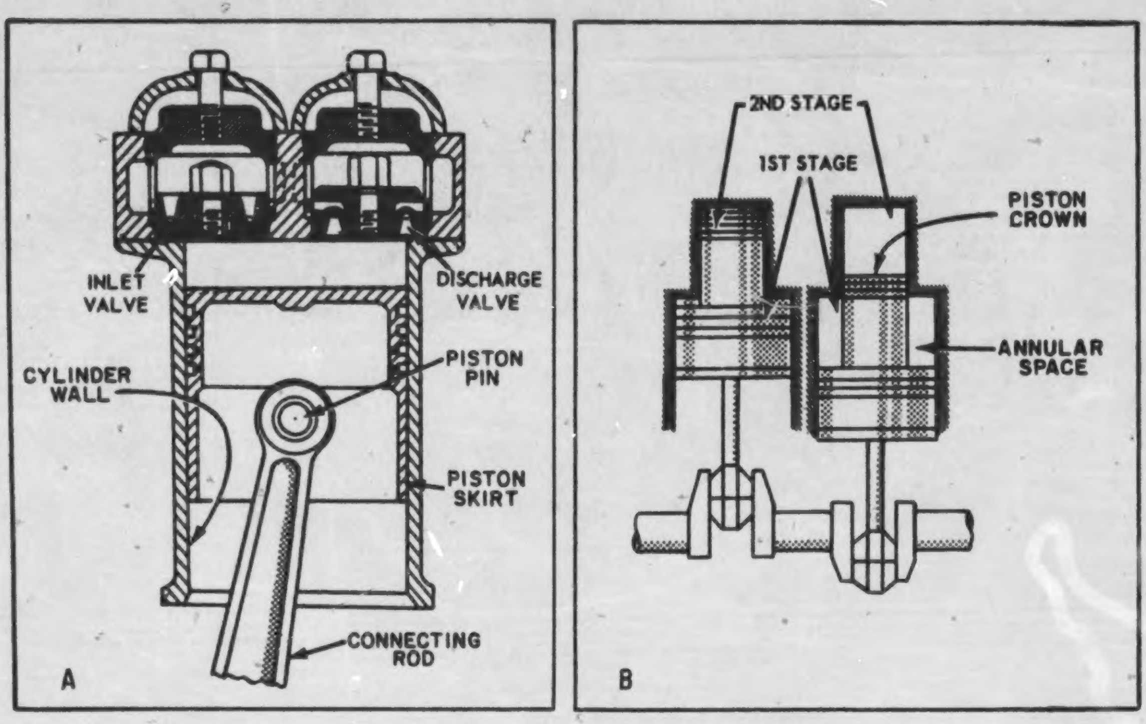
CYLINDERS.—Various designs of cylinders are used, depending primarily upon the number of stages of compression required to produce the maximum discharge pressure. Several common cylinder arrangements for low- and medium-pressure air compressors are shown in part A of figure 16-4. Several arrangements for cylinders and pistons of high-pressure compressors are shown in part B of figure 16-4. The stages are numbered 1 through 4, and a 3- and a 4-stage arrangement are shown. In 5- and 6-stage compressors, the same basic stage arrangement is followed.

PISTONS.—The pistons may be of two types, trunk pistons or differential pistons. TRUNK PISTONS (fig. 16-7A) are driven directly by the connecting rods. Since the upper end of a connecting rod is fitted directly to the piston (also referred to as wrist or trunk pins), there is a tendency for the piston to develop a side pressure against the cylinder walls. To distribute the side pressure over a wide area of the cylinder walls or liners, pistons with long skirts are used. This type of piston minimizes cylinder wall wear.


COMPRESSOR CYLINDER
GUARD
STRIPS
SEAT
AIRFLOW
A
VALVE ASSEMBLY
VALVE COVER
VALVE YOKE
4TH STAGE DISCHARGE AIR CONNECTION
4TH STAGE SUCTION AIR CONNECTION
AIRFLOW
B
KEEPER
SPRING
DISK
SEAT
AIRFLOW
DISCHARGE VALVE ARRANGEMENT
SEAT
DISK
SPRING
KEEPER
SUCTION VALVE ARRANGEMENT
4TH STAGE DISCHARGE VALVE LOCATION
4TH STAGE SUCTION VALVE LOCATION

47.220

Figure 16-6.—High-pressure air compressor valves. (A) Valve arrangement for lower pressure stages (suction shown). (B) Valve arrangement for higher pressure stages (both suction and discharge shown).



47.155

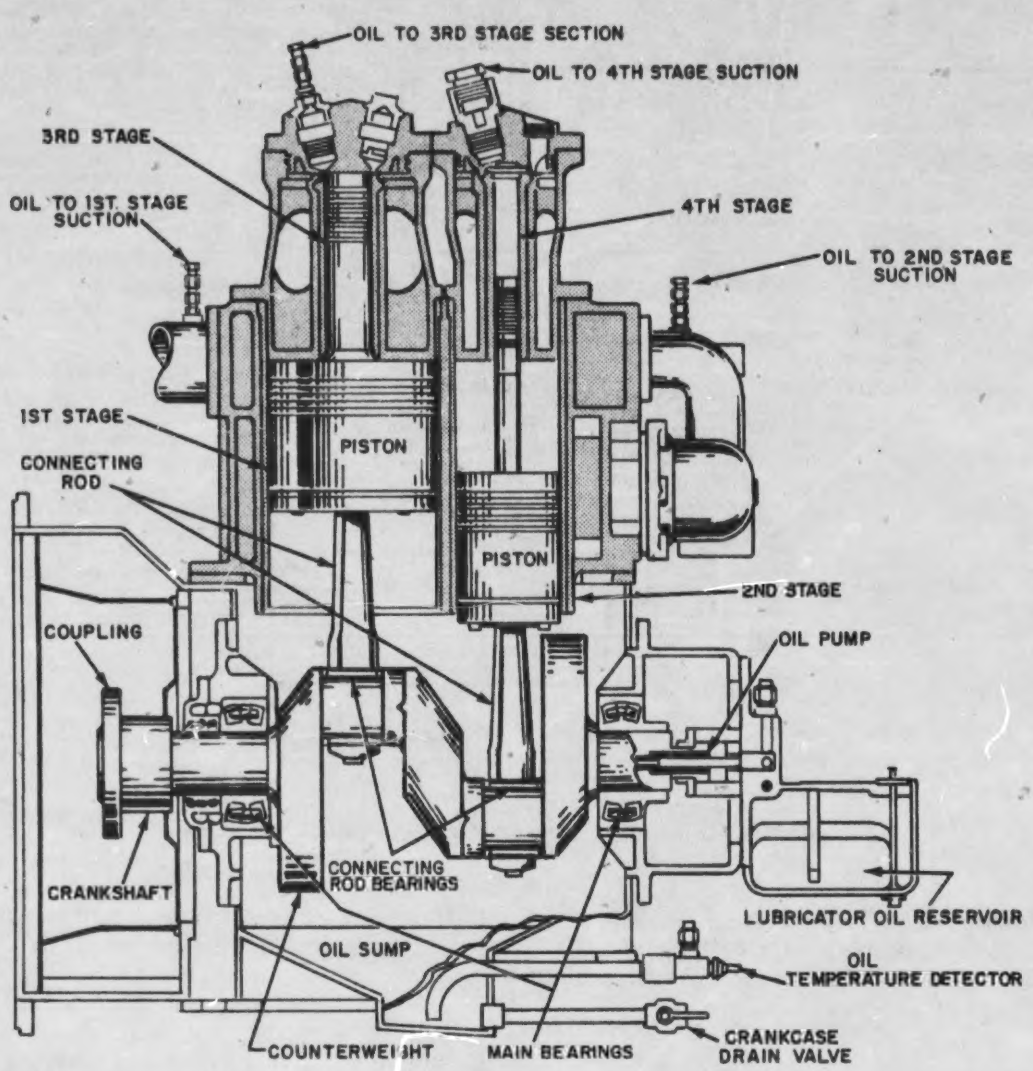
Figure 16-7.—Air compressor pistons. A. Trunk type. B. Differential type.

DIFFERENTIAL PISTONS (fig. 16-7B) are modified trunk pistons having two or more different diameters. These pistons are fitted into special cylinders which are arranged so that more than one stage of compression is achieved by one piston. The compression for one stage takes place over the piston crown; compression for the other stage(s) takes place in the annular space between the large and small diameters of the piston.

Lubrication System

Except for the oil-free nonlubricated compressors, lubrication of high-pressure air compressor cylinders is generally accomplished by means of an adjustable mechanical force-feed lubricator, which is driven from a reciprocating or a rotary part of the compressor. Oil is fed from the cylinder lubricator by separate lines to each cylinder. A check valve is installed at the end of each feed line to keep the compressed air from forcing the oil back into the lubricator. Each feed line is equipped with a sight-glass oil flow indicator. Lubrication begins automatically as the compressor starts up. The amount of oil that must be fed to the cylinder depends on the cylinder diameter, the cylinder wall temperature, and the viscosity of the oil. Figure 16-8 shows the lubrication connections for the cylinders. The type and grade of oil used in compressors is specified in the equipment technical manual and is vital to the operation and reliability of the compressor.

The running gear is lubricated by an oil pump, which is attached to the compressor and is driven from the compressor shaft. This pump (usually of the gear type) draws oil from the reservoir (oil sump) shown in figure 16-8, in the compressor base and delivers it, through a filter, to an oil cooler (if installed). From the cooler,

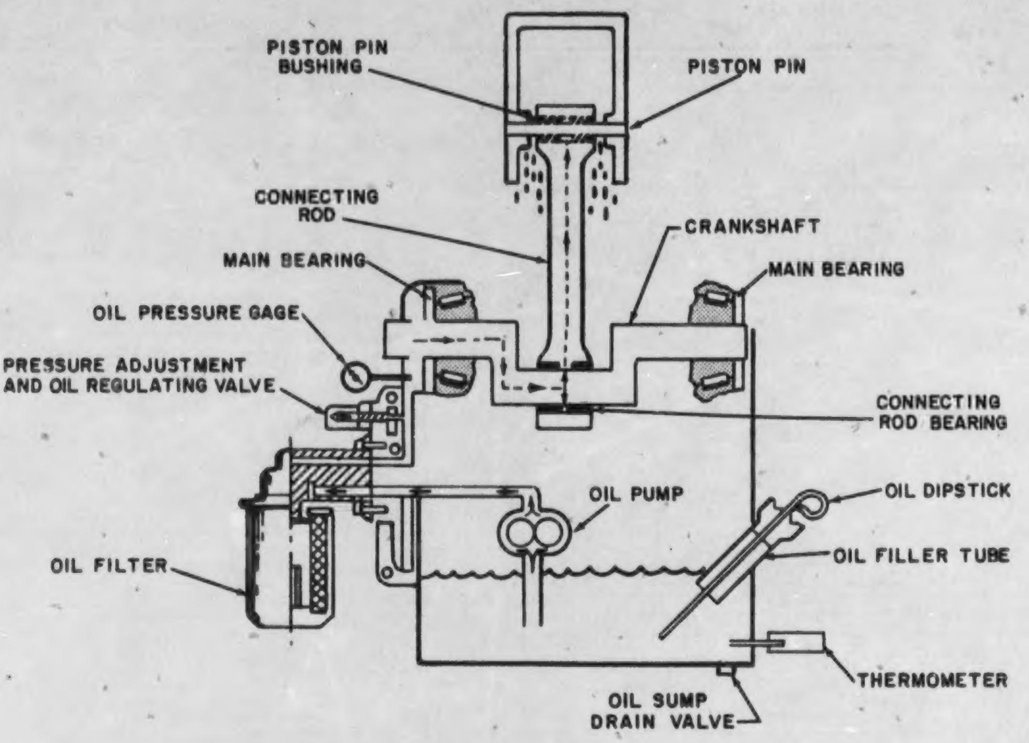

OIL TO 3RD STAGE SECTION
OIL TO 4TH STAGE SUCTION
3RD STAGE
OIL TO 1ST STAGE SUCTION
4TH STAGE
OIL TO 2ND STAGE SUCTION
1ST STAGE
CONNECTING ROD
PISTON
PISTON
2ND STAGE
COUPLING
OIL PUMP
CRANKSHAFT
CONNECTING ROD BEARINGS
LUBRICATOR OIL RESERVOIR
OIL SUMP
OIL TEMPERATURE DETECTOR
CRANKCASE DRAIN VALVE
COUNTERWEIGHT
MAIN BEARINGS

47.221

Figure 16-8.—High-pressure air compressor.

the oil is distributed to the top of each main bearing, to spray nozzles for reduction gears, and to outboard bearings. The crankshaft is drilled so that oil fed to the main bearings is picked up at the main bearing journals and carried to the crank journals. The connecting rods contain passages which conduct lubricating oil from the crank bearings up to the wrist pin bushings. As oil leaks out from the various bearings, it drips back into the oil sump (in the base of the compressor) and is recirculated. Oil from the outboard bearings is carried back to the sump by the drain lines.

Low-pressure air compressor lubrication is shown in figure 16-9. This system is similar to the running gear lubrication system for the high-pressure air compressor.


PISTON PIN BUSHING
PISTON PIN
CONNECTING ROD
CRANKSHAFT
MAIN BEARING
MAIN BEARING
OIL PRESSURE GAGE
PRESSURE ADJUSTMENT AND OIL REGULATING VALVE
CONNECTING ROD BEARING
OIL PUMP
OIL DIPSTICK
OIL FILTER
OIL FILLER TUBE
THERMOMETER
OIL SUMP DRAIN VALVE

47.222

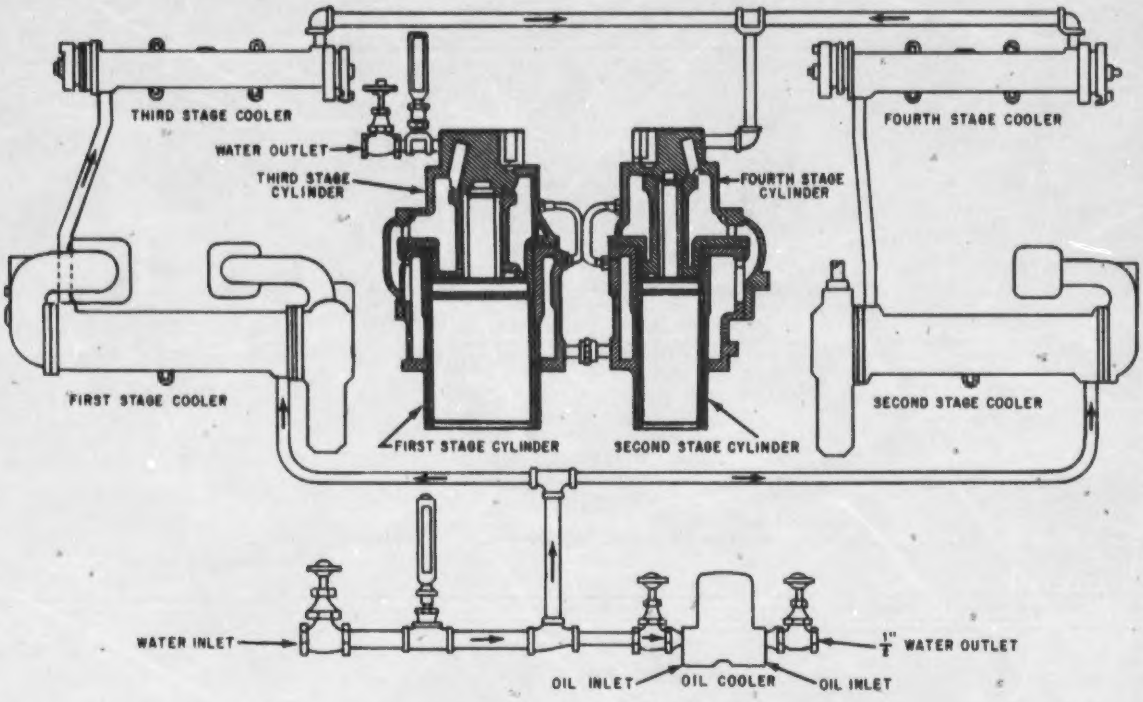
Figure 16-9.—Lubricating Oil System of a low-pressure air compressor.

Nonlubricated reciprocating compressors have lubricated running gear (shaft and bearings) but no lubrication for the pistons and valves. This design produces oil free air.

Cooling Systems

Most high-pressure and medium-pressure compressors are cooled by the ship's auxiliary freshwater or by seawater supplied from the ship's fire main or machinery cooling water service mains. The cooling water is generally supplied to each unit from either of two sources. Compressors located outside the larger machinery spaces may be equipped with an attached circulating water pump as a standby source of cooling water. Small low-pressure compressors used to supply ship's service air and diesel engine starting air and some small capacity high-pressure air compressors are air-cooled by a fan driven by the compressors.

The path of water in the cooling water system of a typical four-stage compressor is illustrated in figure 16-10. Not all cooling water systems have identical path-of-water flow, but in systems equipped with oil coolers it is important that the coldest water be available for circulation through the cooler. Valves are usually provided to control the water to the cooler independently of the rest of the system. Thus, oil temperature can be controlled without harmful effects to other parts of the compressor. Cooling of the air in the intercoolers and aftercoolers is very important, as well as cooling the cylinder jackets and heads. The amount of cooling water required depends on the capacity in cubic feet per minute (cfm) and pressure. High-pressure air compressors require more


THIRD STAGE COOLER
WATER OUTLET
THIRD STAGE CYLINDER
FOURTH STAGE CYLINDER
FOURTH STAGE COOLER
FIRST STAGE COOLER
SECOND STAGE COOLER
FIRST STAGE CYLINDER
SECOND STAGE CYLINDER
WATER INLET
1/2" WATER OUTLET
OIL INLET
OIL COOLER
OIL INLET

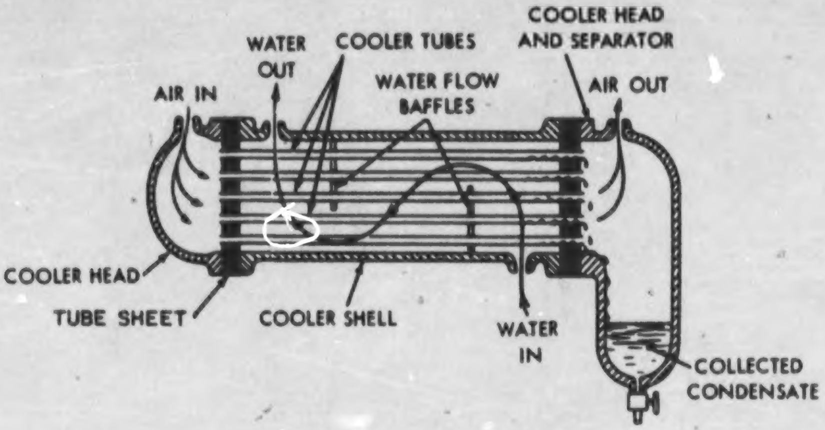
74.157

Figure 16-10.—Cooling water system in a typical multistage air compressor.

cooling water (for the same cfm) than the low-pressure units.

When seawater is used as the cooling agent, all parts of the circulating system must be of corrosion-resistant materials. The cylinders and heads are therefore composed of a bronze alloy with water jackets cast integral with the cylinders. Each cylinder is generally fitted with a liner of special cast iron or steel to withstand the wear of the piston. Wherever practicable, cylinder jackets are fitted with handholes and covers so that the water spaces can be inspected and cleaned. Jumpers are usually used to make water connections between the cylinders and heads because they prevent possible leakage into the compression spaces In some compressors, however, the water passes directly through the joint between the cylinder and the head. With this latter type, the joint MUST be properly gasketed to prevent leakage which, if allowed to continue, will damage the compressor.

The INTERCOOLERS and AFTERCOOLERS remove heat generated during compression and promote condensation of any vapor that may be present. Figure 16-11 is a diagram of a basic cooler and separator unit showing the collected condensate in the separator section. The collected condensate must be drained at regular intervals to prevent carryover into the next stage. Accumulation at low points may cause water hammer, freezing and bursting of pipes in exposed locations, faulty operation of pneumatic tools, and possible damage to electrical apparatus when air is used for cleaning. The removal of heat is also required for economical compression. During compression the temperature of the air increases, thus causing the air to expand to a larger volume which, in turn, requires a corresponding increase of work to compress it. Multistaging, therefore, with interstage cooling of the air, reduces the power requirement for a given capacity.

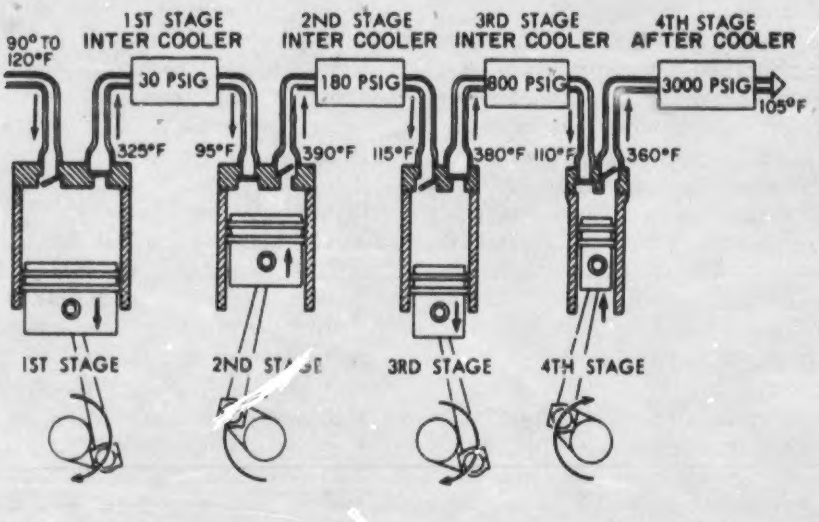

COOLER HEAD AND SEPARATOR
WATER OUT
COOLER TUBES
WATER FLOW BAFFLES
AIR IN
AIR OUT
COOLER HEAD
TUBE SHEET
COOLER SHELL
WATER IN
COLLECTED CONDENSATE

47.223

Figure 16-11.—Basic cooler and separator.

The interstage cooling reduces the maximum temperature in each cylinder and thereby reduces the amount of heat which must be removed by the water jacket at the cylinder. Also, the resulting lower temperature in the cylinder ensures better lubrication of the piston and the valves. Figure 16-12 illustrates the pressures and temperatures through a four-stage compressor. The intercoolers and the aftercoolers (on the output of the final stage) are of the same general construction except that the aftercooler is designed to withstand a higher working pressure than the intercoolers.

Water-cooled intercoolers may be of the straight tube and shell type (fig. 16-11) or, if size dictates, of the coil type. In coolers with an


1ST STAGE INTER COOLER
2ND STAGE INTER COOLER
3RD STAGE INTER COOLER
4TH STAGE AFTER COOLER
90° TO 120°F
30 PSIG
180 PSIG
800 PSIG
3000 PSIG
105°F
325°F
95°F
390°F
115°F
380°F
110°F
360°F
1ST STAGE
2ND STAGE
3RD STAGE
4TH STAGE

47.224

Figure 16-12.—Pressures and temperatures resulting from multistaging and interstage cooling.

air discharge pressure below 250 psi, the air may flow either through the tubes or over and around them. In coolers with an air discharge pressure above 250 psi, the air generally flows through the tubes. In tubular coolers, baffles deflect the air or water in its course through the cooler. In coil-type coolers the air passes through the coil and the water flows around the coils.

Air-cooled intercoolers and aftercoolers may be of the radiator type or may consist of a bank of finned copper tubes located in the path of cooling air supplied by the compressor cooling fan.

Each intercooler and aftercooler is generally fitted with relief valves on both the air and water sides. Water relief valves are usually set 5 psi above the maximum working pressure that may be applied to the system. The air relief valves must be set in accordance with directions given in the Planned Maintenance System, manufacturer's technical manual, or in the *Naval Ships' Technical Manual,* Chapter 551 (9590).

As seen earlier, intercoolers and aftercoolers are normally fitted with moisture separators on the discharge side to remove the condensed moisture and oil from the air stream. The separators are of a variety of designs. Liquid is removed by centrifugal force, impact, or sudden changes in velocity and/or direction of flow of the air stream. Drains on each separator remove the water and oil.

Oil coolers are of the coil type, tube and shell type, or of a variety of commercial types. Although external oil coolers are generally used, some compressors are fitted with a base type oil cooler in which cooling water is circulated through a coil placed in the oil sump. As with the intercoolers and aftercoolers, the materials of the tubes, coils, or cores of these coolers, are made of copper-nickel alloy with shell and tube sheets of bronze composition. On all late model compressors the circulating water system is arranged so that the quantity of cooling water passing through the oil cooler can be regulated without disturbing the quantity of water passing through the cylinder jackets, intercoolers, or aftercoolers. Thermometers or other temperature measuring devices are fitted to the circulating water inlet and outlet connections, to the intake and discharge of each stage of compression, to the final air discharge, and to the oil sump.

Control Systems

The control system of a reciprocating air compressor may include one or more devices for start-stop control, constant-speed control, speed-pressure governing, and automatic high-temperature shut-down devices.

Control or regulating systems for air compressors in use by the Navy are largely of the start-stop type in which the compressor starts and stops automatically as the receiver pressure falls or rises within predetermined setpoints. On electrically driven compressors the system is very simple—the receiver pressure operates against a pressure switch that opens when the pressure upon it reaches a given limit and closes when the pressure drops a predetermined amount. Centrifugal compressors do not have automatic start-stop controls mainly because of their high horsepower. An automatic load/unload control system is used.

On electrically driven units required to start at either of two pressures, as in some of the medium-pressure systems, one of two pressure switches are selected with a three-way valve or cock that admits pressure from the air accumulator to the selected pressure switch. Another method is to direct the air from the receiver through a three-way valve to either of two control valves set for the respective range of pressures. A line is run from each control valve to a single pressure which may be set at any convenient pressure since the setting of the control valve selected will determine the operation of the switch.

The CONSTANT-SPEED CONTROL regulates the pressure in the air receiver by controlling the output of the compressor without stopping or changing the speed of the unit. This control prevents frequent starting and stopping of compressors when there is a fairly constant but low demand for air. Control is provided by directing air to unloading devices through a control valve set to operate at a predetermined pressure.

AUTOMATIC HIGH-TEMPERATURE SHUTDOWN DEVICES are fitted on all recent designs of high-pressure air compressors. Thus, if

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the cooling water temperature rises above a safe limit, the compressor will stop and will not restart automatically. Some compressors are fitted with a device that will shut down the compressor if the temperature of the air leaving any stage exceeds a preset value.

Unloading Systems

Air compressor unloading systems are installed for the removal of all but the friction loads on the compressors; that is, they automatically remove the compression load from the compressor while the unit is starting and automatically apply the load after the unit is up to operating speed. For units having start-stop control, the unloading system is separate from the control system. For compressors equipped with constant-speed control, the unloading and control systems are integral parts of each other.

We cannot give a detailed explanation for every type of unloading device used to unload air compressor cylinders, but you should know something about several of the unloading methods which you will probably encounter. These include closing or throttling the compressor intake, holding intake valves off their seats, relieving intercoolers to the atmosphere, relieving the final discharge to the atmosphere (or opening a bypass from the discharge to the intake), opening up cylinder clearance pockets, using miscellaneous constant-speed unloading devices, and various combinations of these methods.

As an example of a typical compressor unloading device, consider the MAGNETIC TYPE UNLOADER. Figure 16-13 illustrates the unloader valve arrangement. This unloader consists of a solenoid-operated valve connected with the motor starter. When the compressor is at rest, the solenoid valve is deenergized, admitting air from the receiver to the unloading mechanism. When the compressor reaches near-normal speed, the solenoid valve is energized, releasing the pressure from the unloading mechanism and loading the compressor again.

For detailed information on the various unloading devices, refer to the pertinent manufacturers' technical manuals for compressors installed in your ship.

ROTARY-CENTRIFUGAL AIR COMPRESSORS

A nonreciprocating type of air compressor that may be found aboard ship is variously referred to as a rotary compressor, a centrifugal compressor, or a "liquid piston" compressor. Actually, the unit is something of a mixture, operating partly on rotary principles and partly on centrifugal principles; most accurately, perhaps, it might be called a rotary-centrifugal compressor.

The rotary-centrifugal compressor is used to supply low-pressure compressed air. Because this compressor is capable of supply air that is completely free of oil, it is often used as the compressor for pneumatic control systems and for other applications where oil-free air is required.

The rotary-centrifugal compressor, shown in figure 16-14, consists of a round, multibladed rotor which revolves freely in an elliptical casing. The elliptical casing is partially filled with high-purity water. The curved rotor blades project radially from the hub. The blades,

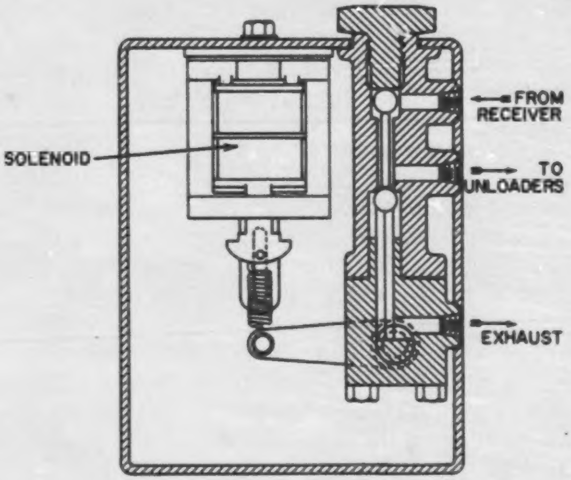

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Figure 16-13.—Magnetic type unloader.

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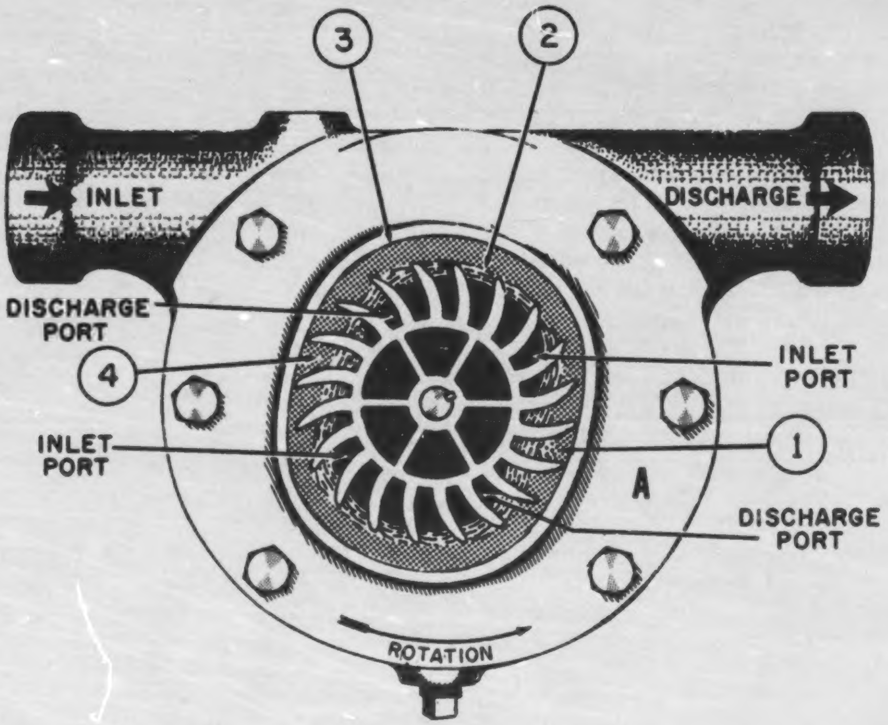

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Figure 16-14.–Rotary-centrifugal compressor.

together with the side shrouds, form a series of pockets or buckets around the periphery. The rotor, which is keyed to the shaft of an electric motor, revolves at a speed high enough to throw the liquid out from the center by centrifugal force, resulting in a solid ring of liquid revolving in the casing at the same speed as the rotor but following the elliptical shape of the casing. This action alternately forces the liquid to enter and recede from the buckets in the rotor at high velocity.

To follow through a complete cycle of operation, look at figure 16-14 and let us start at point A (located at right center). The chamber ① is full of liquid. The liquid, because of centrifugal force, follows the casing, withdraws from the rotor, and pulls air in through the inlet port. At ② the liquid has been thrown outward from the chamber in the rotor and has been replaced with atmospheric air. As the rotation continues, the converging wall ③ of the casing forces the liquid back into the rotor chamber, compressing the trapped air and forcing it out through the discharge port. The rotor chamber ④ is now full of liquid and ready to repeat the cycle which takes place twice in each revolution.

A small amount of water must be constantly supplied to the compressor to make up for that which is carried over with the compressed air. The water which is carried over with the compressed air is removed in a refrigeration-type dehydrator.

COMPRESSED AIR RECEIVERS

An air receiver is installed in each space that houses air compressors (except centrifugal and rotary lobe types). The receiver is an air storage tank. If demand is greater than the compressor capacity, some of the stored air is supplied to the system. If demand is less than the compressor capacity, the excess is stored in the receiver or accumulator until the pressure is raised to its maximum setting, at which time the compressor unloads or stops. Thus, in a compressed air system, the receiver functions to minimize pressure variations in the system and to supply air during peak demand. This will minimize start-stop cycling of air compressors. Air receivers may be horizontal or vertical. Vertically mounted receivers have convex bottoms to permit proper draining of accumulated moisture, oil, and foreign matter. All receivers have such fittings as inlet and outlet connections; drain connections and valves; connections for operating a line to compressor regulators, pressure gages, relief valves (set at approximately 12% above normal working pressure of the receiver); and handhole or manhole plates (depending on the size of the receiver). The discharge line between the compressors and the receiver is as short and straight as possible to eliminate vibration due to pulsations of air and to reduce pressure losses due to friction.

In high-pressure air systems, air receivers are called AIR FLASKS. Air flasks are usually cylindrical in shape, having belled ends and female-threaded necks. The flasks are also constructed in shapes to conform to the hull curvature for installation between hull frames.

One or more air flasks connected together constitute an air BANK.

COMPRESSED AIR SUPPLY SYSTEMS

The remainder of a compressed air system is the piping and valves which distribute the compressed air to the points of use.

HIGH-PRESSURE AIR

Figure 16-15A is an illustration of the first part of a high-pressure air system aboard a surface ship. The 3000/150 psi reducing station is used for emergencies or abnormal situations to provide air to the low-pressure air system.

LOW-PRESSURE AIR

Low-pressure air (sometimes referred to as LP ship's service air) is the most widely used air system aboard the ship. Figure 16-15B is an illustration of the first part of a low-pressure air system. Many of the low-pressure air systems are divided into subsystems, vital and nonvital air.

Vital air is used primarily for engineering purposes such as automatic boiler controls, water level controls, and air pilot-operated control valves. Vital air is also supplied to electronics systems. Vital air systems are split between all main machinery groups with cross-connect capability.

Nonvital air is provided for many different purposes, such as laundry equipment, tank-level indicating systems, and airhose connections. Air for a nonvital air system is supplied through a PRIORITY VALVE, which will shut automatically to secure air to nonvital components when the pressure in the air system drops to a specified setpoint and to reopen to restore nonvital air when pressure in the system returns to normal. This system gives the vital air first priority on all the air in the low-pressure system.

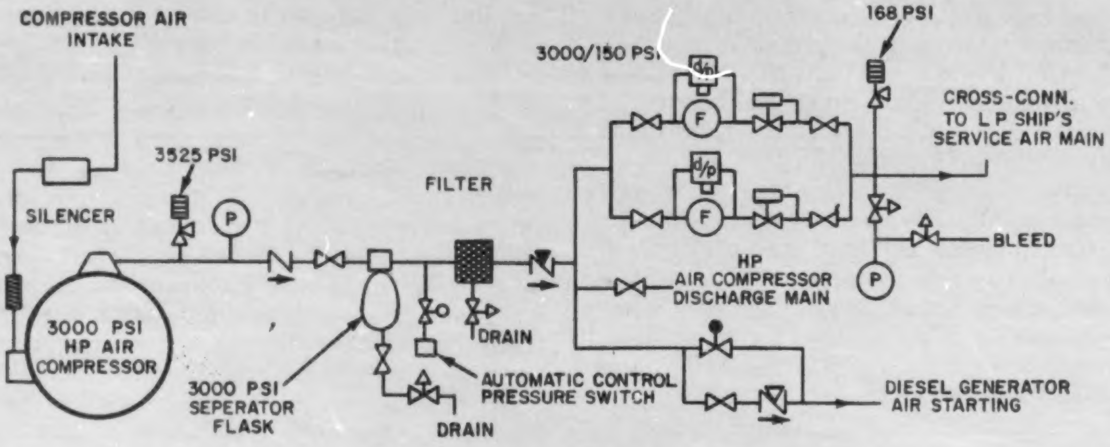
PRAIRIE-MASKER AIR SYSTEMS

A special purpose air system installed in many surface ships is the prairie-masker air system. This system supplies "disguise" air to a system of emitter rings or belts surrounding the hull and to the propeller blades through the propulsion shafts.

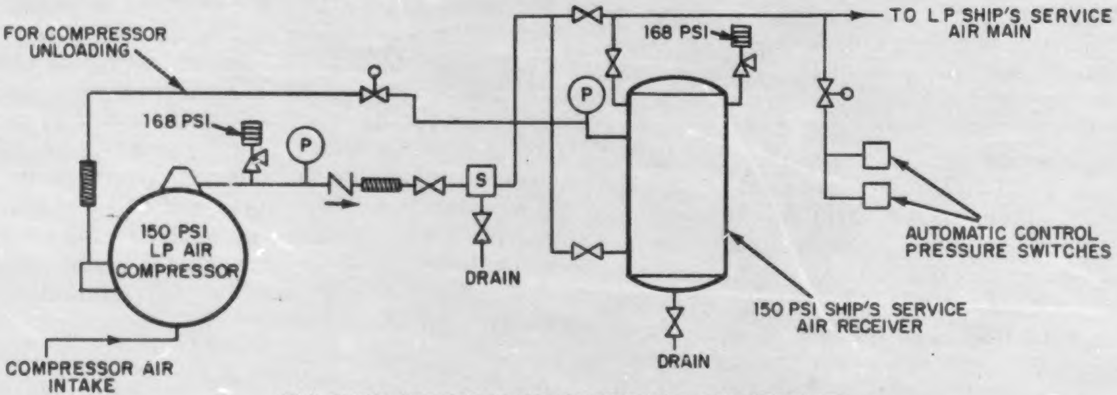
The emitter rings contain small holes which release the masker air into the sea, coating the hull with air bubbles.

The prairie air passing through the propulsion shafts is emitted to sea by small holes in the propeller blades.

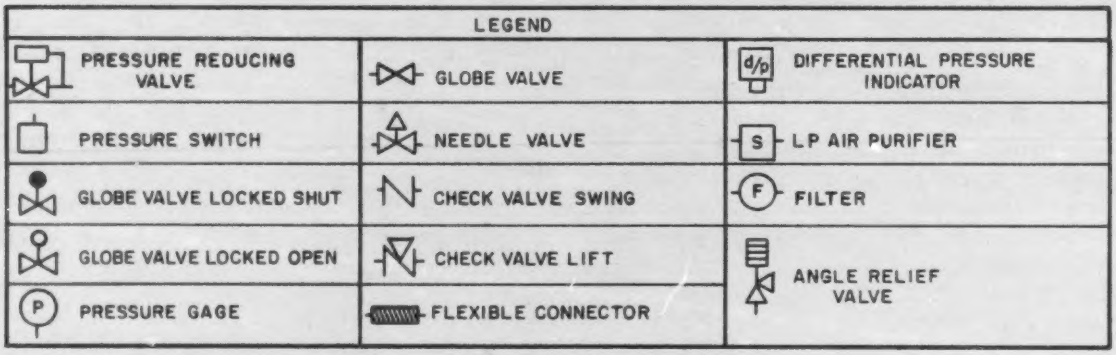
The air supply for the prairie-masker system is provided by a turbocompressor. The turbocompressor is composed of the following five major parts contained in one compact unit: turbine-driven compressor, lube water tanks, air inlet silencer, lube water system and control system.


COMPRESSOR AIR INTAKE
SILENCER
3525 PSI
P
3000 PSI HP AIR COMPRESSOR
3000 PSI SEPERATOR FLASK
FILTER
DRAIN
AUTOMATIC CONTROL PRESSURE SWITCH
DRAIN
3000/150 PSI
d/p
F
d/p
F
168 PSI
CROSS-CONN. TO L P SHIP'S SERVICE AIR MAIN
BLEED
HP AIR COMPRESSOR DISCHARGE MAIN
P
DIESEL GENERATOR AIR STARTING

(A) HP AIR COMPRESSOR AND CROSS CONNECTION REDUCING STATION


FOR COMPRESSOR UNLOADING
168 PSI
P
150 PSI LP AIR COMPRESSOR
COMPRESSOR AIR INTAKE
S
DRAIN
P
168 PSI
TO L P SHIP'S SERVICE AIR MAIN
AUTOMATIC CONTROL PRESSURE SWITCHES
150 PSI SHIP'S SERVICE AIR RECEIVER
DRAIN

(B) SHIP'S SERVICE LP AIR COMPRESSOR AND RECEIVER



LEGEND		
PRESSURE REDUCING VALVE	GLOBE VALVE	d/p DIFFERENTIAL PRESSURE INDICATOR
PRESSURE SWITCH	NEEDLE VALVE	S LP AIR PURIFIER
GLOBE VALVE LOCKED SHUT	CHECK VALVE SWING	F FILTER
GLOBE VALVE LOCKED OPEN	CHECK VALVE LIFT	ANGLE RELIEF VALVE
P PRESSURE GAGE	FLEXIBLE CONNECTOR	

47.225

Figure 16-15.—HP and LP air compressor piping arrangements.

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The turbine-driven compressor consists of a single-stage centrifugal compressor driven by a single-stage impulse turbine. The compressor impeller and the turbine wheel are mounted at opposite ends of the same shaft. Two water-lubricated bearings support the rotor assembly. The compressor runs at speeds approaching 40,000 rpm. A control system for the unit provides constant steam admission, overspeed trip, overspeed alarm, low lube pressure trip and alarm, and a high lube water temperature alarm.

MOISTURE REMOVAL

The removal of moisture from compressed air is in an important part of compressed air systems. If air at atmospheric pressure, with even a very low relative humidity, is compressed to 3,000 psi or 4,500 psi, it becomes saturated with water vapor. Some moisture is removed by the intercoolers and aftercoolers as seen earlier in the chapter. Also, air flasks, receivers and banks are provided with low point drains to periodically drain any collected moisture. However, many shipboard uses of air require air with an even smaller moisture content than is obtained through these methods. In addition, moisture in air lines can create other problems which are potentially hazardous, such as the freezing up of valves and controls. This can occur, for example, if very high-pressure air is throttled to a very low pressure at a high flow rate. The venturi effect of the throttled air produces very low temperatures which will cause any moisture in the air to freeze into ice, making the valve (especially an automatic valve) either very difficult or impossible to operate. Also, droplets of water in an air system with a high pressure and high flow rate can cause serious water hammer within the system. For these reasons, air dryers or dehydrators are used to dry the compressed air. Two basic types of air dehydrators are in use: the desiccant type and the refrigerated type.

Desiccant Type Dehydrators

A desiccant is a drying agent. More practically, a desiccant is a substance with a high capacity to remove (absorb) water or moisture and also a high capacity to give off that moisture so that the desiccant can be reused.

In compressed air system dehydrators, a pair of dessicant towers (flasks full of desiccant) are used. One is on service dehydrating the compressed air while the other is being "reactivated." A desiccant tower is normally reactivated by passing dry, heated air through the tower being reactivated in the direction opposite to normal dehydration airflow. The hot air evaporates the collected moisture and carries it out of the tower to the atmosphere. The purge air is heated by electrical heaters. Once the tower that is reactivating has completed the reactivation cycle, it is placed on service to dehydrate air and the other tower is reactivated.

Another type of desiccant dehydrator in use is the Heat-Les Dryer. These units require no electrical heaters or external source of purge air to operate. Figure 16-16A shows the compressed air entering at the bottom of the left tower, passing upward through the desiccant where it is dried to a very low moisture content. The dry air passes through the check valve to the dry air outlet. Simultaneously, a small percentage of the dry air is passed through the orifice between the towers and flows down through the right tower, reactivating the desiccant and passing out through the purge exhaust. At the end of the cycle, the towers are automatically reversed, as shown in part B of figure 16-16.

Refrigerated Type Dehydrators

Another method of removing moisture from compressed air is through the use of refrigeration. If we pass the compressed air over a set of refrigerated cooling coils, oil and moisture vapors will condense from the air and can be collected and removed via a low point drain.

Some installations may use a combination of a refrigerated dehydrator and desiccant dehydrators to purify the compressed air.

COMPRESSED AIR PLANT OPERATION AND MAINTENANCE

The operation of any air compressor or air system must be done in strict compliance with

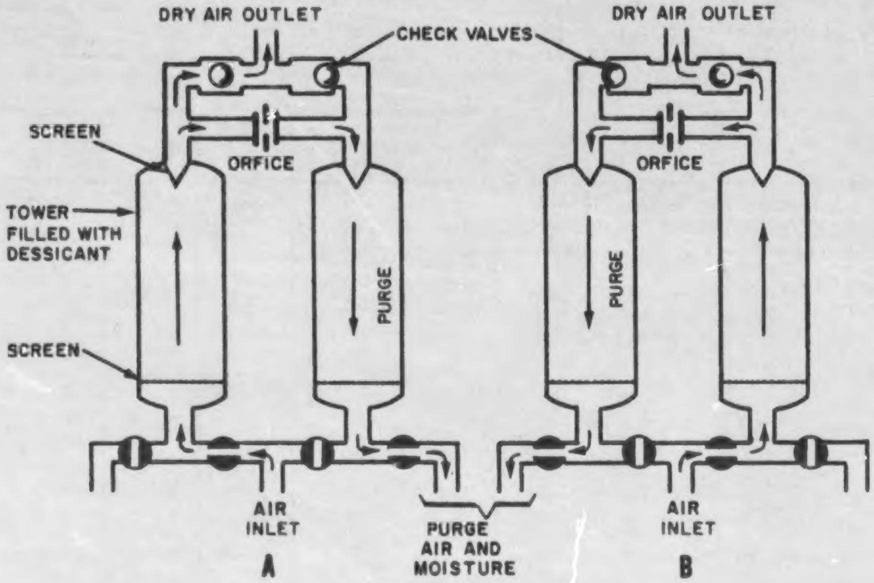

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Figure 16-16.—Heat-Les dehydrator.

approved operating procedures. Compressed air is potentially very dangerous. Cleanliness is of utmost importance in all maintenance that requires opening compressed air systems.

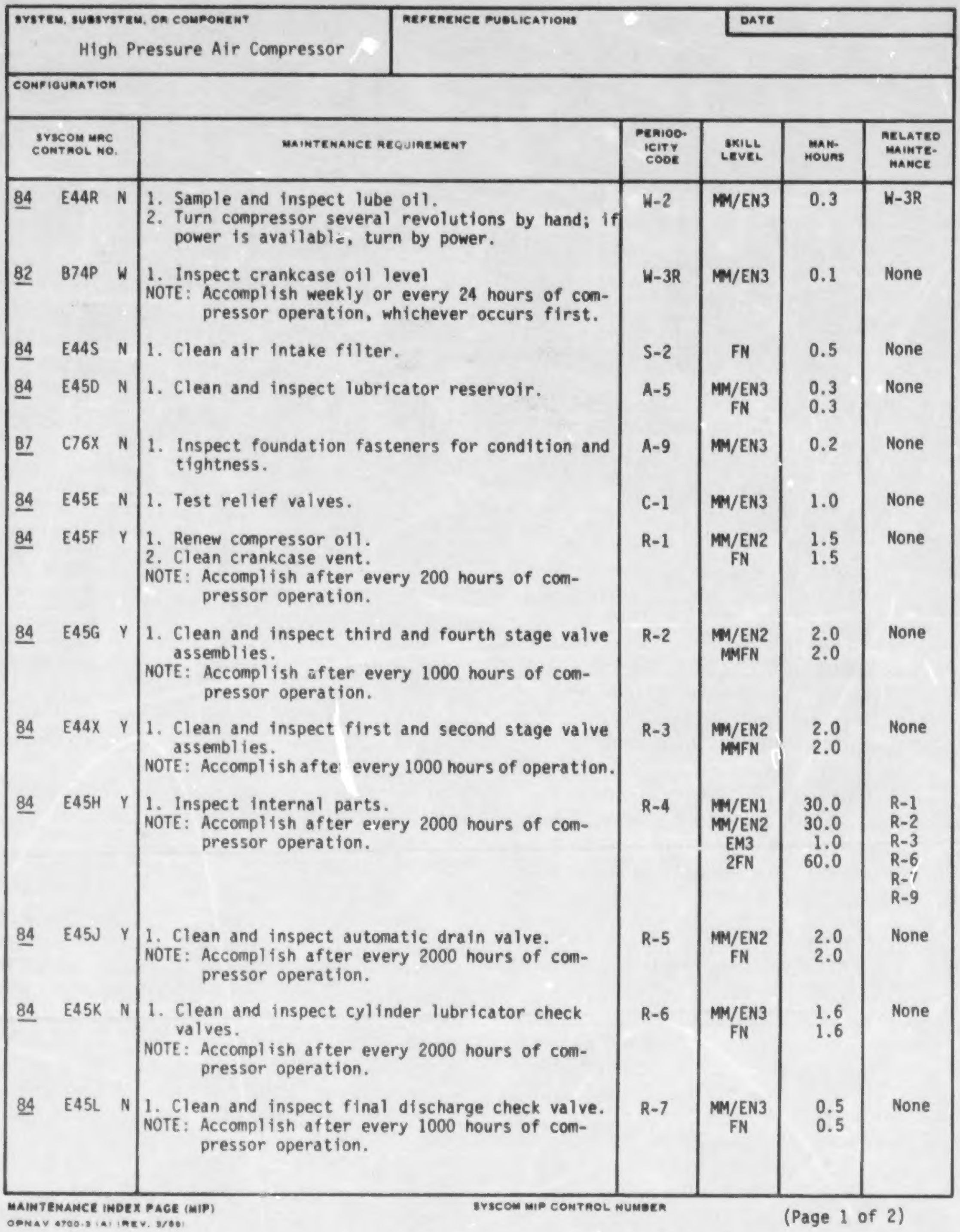
Figure 16-17 is a Maintenance Index Page (MIP) for one design and make of high-pressure air compressor. This will give you an idea of the planned maintenance required on an air compressor.

SAFETY PRECAUTIONS

There are many hazards associated with pressurized air, particularly high-pressure air. Serious explosions have occurred in high-pressure air systems because of diesel effect. If a portion of an unpressurized system or component is suddenly and rapidly pressurized with high-pressure air, a large amount of heat is produced. If the heat is excessive, the air may reach the ignition temperature of the impurities present in the air and piping (oil, dust, etc). When the ignition temperature is reached, a violent explosion will occur as these impurities ignite. In addition, ignition temperatures may result from rapid pressurization of a low-pressure dead end portion of the piping system, malfunctioning of compressor aftercoolers, leaky or dirty valves, and many other causes. Every precaution must be taken to have only clean, dry air at the compressor inlet.

Air compressor accidents have also been caused by improper maintenance procedures such as disconnecting parts while they are under pressure, replacing parts with units designed for lower pressures, and installing stop valves or check valves in improper locations. Improper operating procedures have also caused air compressor accidents with resulting serious injury to personnel and damage to equipment.

To minimize the hazards inherent in the process of compression and in the use of compressed air, all safety precautions outlined in the manufacturers' technical manuals and in *Naval Ships' Technical Manual,* Chapter 551



SYSTEM, SUBSYSTEM, OR COMPONENT High Pressure Air Compressor	REFERENCE PUBLICATIONS	DATE
CONFIGURATION		

SYSCOM MRC CONTROL NO.	MAINTENANCE REQUIREMENT	PERIODICITY CODE	SKILL LEVEL	MAN-HOURS	RELATED MAINTENANCE
84 E44R N	1. Sample and inspect lube oil. 2. Turn compressor several revolutions by hand; if power is available, turn by power.	W-2	MM/EN3	0.3	W-3R
82 B74P W	1. Inspect crankcase oil level NOTE: Accomplish weekly or every 24 hours of compressor operation, whichever occurs first.	W-3R	MM/EN3	0.1	None
84 E44S N	1. Clean air intake filter.	S-2	FN	0.5	None
84 E45D N	1. Clean and inspect lubricator reservoir.	A-5	MM/EN3 FN	0.3 0.3	None
B7 C76X N	1. Inspect foundation fasteners for condition and tightness.	A-9	MM/EN3	0.2	None
84 E45E N	1. Test relief valves.	C-1	MM/EN3	1.0	None
84 E45F Y	1. Renew compressor oil. 2. Clean crankcase vent. NOTE: Accomplish after every 200 hours of compressor operation.	R-1	MM/EN2 FN	1.5 1.5	None
84 E45G Y	1. Clean and inspect third and fourth stage valve assemblies. NOTE: Accomplish after every 1000 hours of compressor operation.	R-2	MM/EN2 MMFN	2.0 2.0	None
84 E44X Y	1. Clean and inspect first and second stage valve assemblies. NOTE: Accomplish after every 1000 hours of operation.	R-3	MM/EN2 MMFN	2.0 2.0	None
84 E45H Y	1. Inspect internal parts. NOTE: Accomplish after every 2000 hours of compressor operation.	R-4	MM/EN1 MM/EN2 EM3 2FN	30.0 30.0 1.0 60.0	R-1 R-2 R-3 R-6 R-7 R-9
84 E45J Y	1. Clean and inspect automatic drain valve. NOTE: Accomplish after every 2000 hours of compressor operation.	R-5	MM/EN2 FN	2.0 2.0	None
84 E45K N	1. Clean and inspect cylinder lubricator check valves. NOTE: Accomplish after every 2000 hours of compressor operation.	R-6	MM/EN3 FN	1.6 1.6	None
84 E45L N	1. Clean and inspect final discharge check valve. NOTE: Accomplish after every 1000 hours of compressor operation.	R-7	MM/EN3 FN	0.5 0.5	None

MAINTENANCE INDEX PAGE (MIP)
OPNAV 4700-3 (A) (REV. 3/80)

SYSCOM MIP CONTROL NUMBER

(Page 1 of 2)

Figure 16-17.—MIP for a high-pressure air compressor (front).

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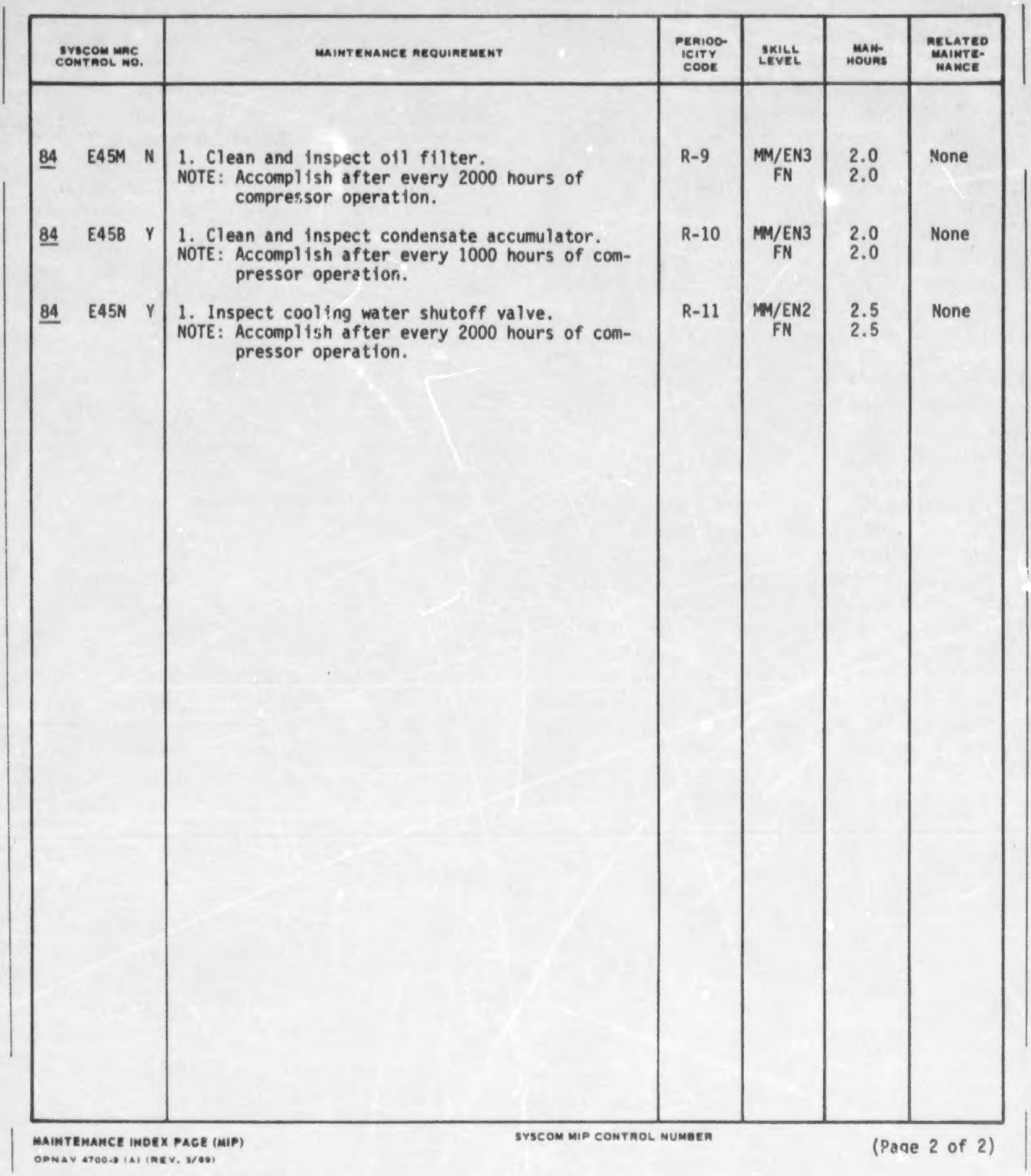

SYSCOM MRC CONTROL NO.	MAINTENANCE REQUIREMENT	PERIODICITY CODE	SKILL LEVEL	MAN-HOURS	RELATED MAINTENANCE
84 E45M N	1. Clean and inspect oil filter. NOTE: Accomplish after every 2000 hours of compressor operation.	R-9	MM/EN3 FN	2.0 2.0	None
84 E45B Y	1. Clean and inspect condensate accumulator. NOTE: Accomplish after every 1000 hours of compressor operation.	R-10	MM/EN3 FN	2.0 2.0	None
84 E45N Y	1. Inspect cooling water shutoff valve. NOTE: Accomplish after every 2000 hours of compressor operation.	R-11	MM/EN2 FN	2.5 2.5	None

MAINTENANCE INDEX PAGE (MIP)
OPNAV 4700-3 (A) (REV. 3/69)

SYSCOM MIP CONTROL NUMBER

(Page 2 of 2)

98.171

Figure 16-17.—MIP for a high-pressure air compressor (back).

(9590) must be strictly observed. Some of these hazards and precautions are:

1. Explosions may be caused by dust laden air or by oil vapor in the compressor or receiver. The explosions are triggered by abnormally high temperatures, which may be caused by leaky or dirty valves, excessive pressurization rates, and faulty cooling systems.

2. NEVER use distillate fuel oil or gasoline as a degreaser to clean compressor intake filters, cylinders, or air passages. These oils vaporize easily and will form a highly explosive mixture with the air under compression.

3. Secure a compressor immediately if you observe that the temperature of the air discharged from any stage rises unduly or exceeds the maximum temperature recommended.

4. NEVER leave the compressor station after starting the compressor unless you are sure that the control, unloading, and governing devices are operating properly.

5. To prevent damage due to overheating, compressors must NOT run at excessive speeds. Proper cooling water circulation must be maintained.

6. If the compressor is to remain idle for any length of time and is in an exposed position in freezing weather, the compressor circulating water system should be thoroughly drained.

7. Before working on a compressor, be sure that the compressor is secured and cannot start automatically or accidentally. The compressor should be blown down completely, then, all valves (including control or unloading valves) between the compressor and the receiver should be secured. Appropriate tag-out procedures for the compressor control and the isolation valves must be followed. Leave the pressure gages open at all times.

8. When cutting air into the whistle, siren, or a piece of machinery, be sure the supply line to the equipment has been properly drained of moisture. When securing the supply of air to the affected equipment, be sure all drains are left open.

9. Prior to disconnecting any part of an air system, be sure that the part is not under pressure. Pressure gage cutout valves should always be left open to the sections to which they are attached.

10. Avoid rapid operation of manual valves. The heat of compression caused by sudden flow of high pressure into an empty line or vessel can cause an explosion if oil or other impurities are present. Valves should be slowly cracked open until flow is noted and should be kept in this position until pressures on both sides have equalized. The rate of pressure rise should be kept under 200 psi per second.

CHAPTER 17

DISTILLING PLANTS

A naval ship must be self-sufficient in producing freshwater. Freshwater demands include water for boiler/steam generator feed, drinking, cooking, bathing, washing, and cleaning. Space limitations permit only enough storage tanks for a couple of days' supply. The ship, therefore, depends on distilling plants to produce large quantities of freshwater of high purity from seawater.

PRINCIPLES OF DISTILLATION

The principle by which these machines (distilling plants) produce freshwater from seawater is quite simple. Even though there are several different types of distilling plants, each of which may appear very complicated at first sight, they all work on the same principles. When water is boiled, it gives off steam vapor, which is relatively free of salt and minerals. The distillation process consists of heating seawater to the boiling point and condensing the vapor (steam) into freshwater, leaving behind the impurities of the seawater. The distillation process for a shipboard plant is illustrated very simply in figure 17-1. Notice that the seawater after boiling is identified as brine.

Seawater is a solution of water and various minerals and salts. In addition to these dissolved solids, seawater contains suspended matter such as vegetable and animal growths and bacteria and other microorganisms. When properly operated, naval distilling plants are capable of producing freshwater that contains only slight traces of chemical salts and no biological contaminants.

Distilling plants are not effective, however, in removing volatile gases or liquids which have a lower boiling point than water. These dissolved gases and liquids will simply boil into the vapor and be combined with the freshwater (distillate). In addition, distilling plants are not effective in killing ALL microorganisms. Naval distilling plants operate at low pressures and, consequently, the boiling temperatures are also low; the distillate, then, is not sterilized by the boiling process. For these reasons, very definite restrictions are placed on the operation of distilling plants in contaminated waters.

At this point, we need to mention the problem of distilling plant "carryover." Practically all cases of high salinity (salt content) in the distillate (freshwater) output of a distilling unit will be caused either by internal seawater leakage (from a tube or basket, etc) or

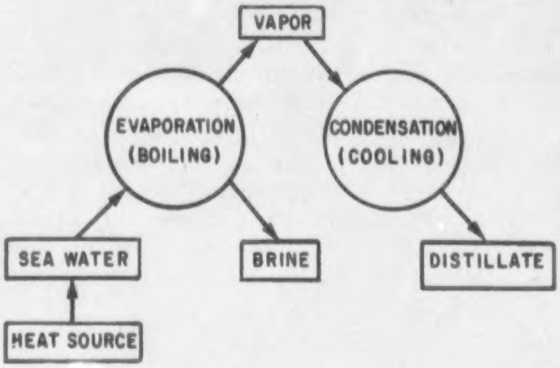

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Figure 17-1.—Simplified diagram of shipboard distillation process.

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by carryover. Carryover actually consists of droplets of seawater which are not filtered out of the vapor produced in a distilling plant before the vapor is condensed into distillate. All types of distilling plants have some type of device to prevent carryover, usually called moisture separators or vapor separators. If the plant is operated improperly, such as attempts to increase the output of the plant beyond rated capacity, the moisture or vapor separators will not function properly and some seawater will pass through them. This will show up as high salinity in the distillate.

Salinity, which is due to chemical salts in seawater, is undesirable. Chemical salts in boiler feedwater will cause corrosion of the tubes of boilers and steam generators. In addition, the normal operating temperature of a naval distilling plant may not be high enough to completely sterilize the distillate. Therefore, any carryover (or leakage) of seawater is a potential HEALTH HAZARD because of the many types of microorganisms (primarily coliform bacteria) which may be present. For these reasons restrictions are placed on the operation of distilling plants aboard ships in either contaminated water or freshwater. Freshwater carryover may not have sufficient salinity to cause either the operator or the salinity indicating system to detect it. Restrictions for operation under these conditions are found in chapter 531 (9580) of the *Naval Ships' Technical Manual.*

There are two reasons that naval distilling plants are designed to operate at low pressures and low boiling temperatures. One reason is that low temperatures help to prevent the formation of harmful scale. Scale is formed when certain sea salts crystallize out of solution at high temperatures. The other reason is that a low pressure plant is more efficient because less heat is required to raise the temperature of the feedwater (seawater) to make it boil; therefore, less heat is wasted by the plant.

COMMON TERMS

Before getting into the discussion of the process of distillation, you should familiarize yourself with the terms defined in the following paragraphs. These terms apply basically to all types of distilling plants now in naval service.

DISTILLATION: The process of boiling seawater and then cooling and condensing the resulting vapor to produce freshwater.

EVAPORATION: The process of boiling seawater to separate it into freshwater vapor and brine. Note that evaporation is the first half of the process of distillation.

CONDENSATION: The process of cooling the freshwater vapor produced by evaporation to produce usable freshwater. Note that condensation is the second half of the process of distillation.

FEED: The seawater, which is the raw material of the distilling unit; also called SEAWATER FEED or EVAPORATOR FEED. Be careful how you use these terms. Do not confuse the "feed" (water) for the distilling units with the "feed" (water) for the boilers. Feed for the distilling units is nothing but raw seawater. Feed for the boilers or steam generators is distilled water of very high purity.

VAPOR: The product of the evaporation of seawater feed.

DISTILLATE: The product resulting from the condensation of the steam (vapor) produced by the evaporation of seawater. Distillate may also be referred to by different names such as FRESHWATER, FRESHWATER DISTILLATE, or CONDENSATE. Try to avoid using the term CONDENSATE to prevent confusion between the condensate of the distilling plant and the condensate in the main and auxiliary condensers. DISTILLATE is the preferred term when you refer to the product of a distilling plant.

BRINE: As seawater feed is evaporated in the distilling plant, the concentration of chemical salts in the remaining seawater feed becomes greater. Any water in which the concentration of chemical salts is higher than it is in seawater is called brine.

SALINITY: The concentration of chemical salts in water is called salinity and is measured by electrical devices, called salinity cells, in units of either epm (equivalents per million) or ppm (parts per million).

EFFECT: In a distilling plant, an effect is that part of a unit where a distillation process occurs. For example, the first place where boiling (or evaporation) of feed into vapor occurs is in the first effect. Most distilling plants are multiple effect types (two, three, four, or five effects). This means that the feed is boiled more than once within the plant. An effect may also be referred to as a STAGE.

SATURATED STEAM: The properties of saturated steam are defined in Table 17-1 according to pressure and temperature.

SUPERHEATED STEAM: Vapor which is not adjacent or next to its liquid source and has been heated to a temperature above its saturation temperature.

DEGREE OF SUPERHEAT: The temperature difference of a superheated vapor between its saturation temperature and its existing temperature.

Let's take an example where the steam pressure past an orifice is 16 in. Hg and auxiliary exhaust steam temperature is 240°F (116°C). Table 17-1 gives the properties of saturated steam. Look in the column labeled "Vacuum Inches of Hg Gage" and find 16.69 and 15.67. By interpolation (estimation), we find the saturation temperature (at the right) to be 176°F (80°C). However, the auxiliary exhaust steam is approximately 240°F (116°C). In this case, then, there is about 64°F (36°C) of superheat in the incoming steam (240°F - 176°F = 64°F).

TYPES OF DISTILLING PLANTS

Distilling plants installed in naval ships are of three general types: (1) vapor compression, (2) low-pressure steam, and (3) heat recovery. The major differences between the three types are the kinds of energy used to operate the units and the pressure under which distillation takes place. Vapor compression units use electrical energy (for heaters and a compressor); low-pressure steam distilling units use low-pressure steam from either the auxiliary exhaust steam systems or the auxiliary steam system. Heat recovery distilling units use diesel engine jacket water as the heat source instead of steam. In addition, vapor compression units boil the feedwater at a pressure slightly above atmospheric pressure while the low-pressure steam and heat recovery units depend on a relatively high vacuum for operation.

The vapor compression type distilling unit is used in submarines and small diesel-driven surface craft where the daily requirements do not exceed 4,000 gallons per day (gpd). The vapor compression type on surface craft is being replaced with the heat recovery distilling units and for this reason vapor compression distilling units will not be covered in this manual. Chapter 531 (9580-II) of *NAVSHIPS' Technical Manual* contains information on these plants.

The low-pressure steam distilling unit is used in all steam-driven surface ships and nuclear submarines. Enginemen usually share responsibility with Machinist's Mates for the maintenance and operation of the low-pressure steam distilling plants.

Low-pressure steam distilling units are "low pressure" from two points of view: First, they use low-pressure steam as the source of energy; and second, their operating shell pressure is less than atmospheric pressure.

There are three major types of low-pressure steam distilling units: (1) submerged tube, (2) flashtype, and (3) vertical basket.

SUBMERGED TUBE DISTILLING PLANTS

The Navy uses three classifications, or arrangements of submerged tube distilling plants: (1) two-shell double–effect, (2) Soloshell double-effect, and (3) triple-effect. The principal difference between the double-effect type and the triple-effect type is the number of stages of evaporation.

In a submerged tube distilling plant feed floods into the bottom of the unit and surrounds the tubes which contain circulating

Table 17-1.—Properties of Saturated Steam

Absolute Pressure			Temperature	
Lb. per Sq. In.	Inches of Hg	Vacuum Inches of Hg Gage	°C	°F
0.20	0.41	29.51	11.74	53.14
0.25	0.51	29.41	15.17	59.30
0.30	0.61	29.31	18.04	64.47
0.35	0.71	29.21	20.52	68.93
0.40	0.81	29.11	22.70	72.86
0.45	0.92	29.00	24.66	76.38
0.50	1.02	28.90	26.43	79.58
0.60	1.22	28.70	29.56	85.21
0.70	1.43	28.49	32.27	90.08
0.80	1.63	28.29	34.66	94.38
0.90	1.83	28.09	36.80	98.24
1.0	2.04	27.88	38.74	101.74
1.2	2.44	27.48	42.18	107.92
1.4	2.85	27.06	45.14	113.26
1.6	3.26	26.66	47.77	117.99
1.8	3.66	26.26	50.13	122.23
2.0	4.07	25.85	52.27	126.08
2.2	4.48	25.44	54.23	129.62
2.4	4.89	25.03	56.05	132.89
2.6	5.29	24.63	57.74	135.94
2.8	5.70	24.22	59.33	138.79
3.0	6.11	23.81	60.82	141.48
3.5	7.13	22.79	64.21	147.57
4.0	8.14	21.78	67.21	152.97
4.5	9.16	20.76	69.91	157.83
5.0	10.18	19.74	72.36	162.24
5.5	11.20	18.72	74.61	166.30
6.0	12.22	17.70	76.70	170.06
6.5	13.23	16.69	78.64	173.56
7.0	14.25	15.67	80.47	176.85
7.5	15.27	14.65	80.52	176.94
8.0	16.29	13.63	83.81	182.86
8.5	17.31	12.61	85.36	185.64
9.0	18.32	11.60	86.82	188.28
9.5	19.34	10.58	88.22	190.80
10.0	20.36	9.56	89.57	193.21
11.0	22.40	7.52	92.08	197.75
12.0	24.43	5.49	94.42	201.96
13.0	26.47	3.45	96.60	205.88
14.0	28.50	1.42	98.64	209.56

low-pressure steam. The steam in the tubes causes the surrounding feed to boil and produce steam (vapor). The vapor passes up into the moisture separators where any entrained seawater droplets are removed. The clean vapor then passes on and is condensed into distillate. Submerged tube-type distilling plants are found on older ships. To explain the principle of distillation in a submerged tube plant, we shall use the Soloshell double-effect plant as an example.

As the name implies, the Soloshell double-effect plant (fig. 17-2) is a double-effect distilling unit contained in a single shell. A division plate separates the two effects. Each effect has a set or "nest" of steam tubes in the bottom of its shell and a vapor separator unit in the upper part of its shell.

Follow along in figure 17-3 (foldout #1 at end of chapter) as we trace the feed through several circuits on its way to becoming distillate. You may have to go through this material a few times before you get the "big picture," but stick with it.

Steam Circuit

Find exhaust steam at midleft of figure 17-3 and trace it to the tubes of the first-effect via a reducing valve. This steam may be from either the auxiliary exhaust steam or the auxiliary steam system, according to plant alignment. The reducing valve controls steam pressure into the tube at approximately 5 psi. The steam must also pass through an orifice plate which controls the quantity of steam admitted to the tubes. The output capacity of the plant can be altered by changing the size of the orifice plate. By passing through the orifice plate, the steam pressure is decreased to a vacuum. This is caused

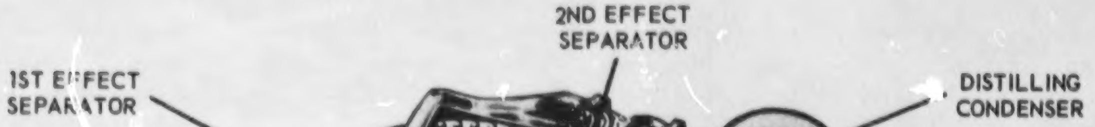
2ND EFFECT SEPARATOR
1ST EFFECT SEPARATOR
DISTILLING CONDENSER
VAPOR FEED HEATER
AIR BAFFLE
SIGHT GLASS
2ND EFFECT TUBES
1ST EFFECT TUBES
FLASH CHAMBER
BRINE PUMP SUCTION
1ST EFFECT DRAIN REGULATOR
DIVISION PLATE
2ND EFFECT DRAIN REGULATOR

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Figure 17-2.—Internal construction of a Soloshell double-effect distilling plant.

by the throttling (expanding) action of the orifice. Since the temperature of the steam is still at saturation temperature for existing auxiliary exhaust pressure, the steam is now superheated. Therefore, the steam is desuperheated in the inlet line by a spray of water from the tube nest drain pump. The desuperheated steam then passes on through the first-effect tubes. The steam in the tubes is indicated on the figure by the black dashed line. The first-effect tubes can be seen in detail in figure 17-2. The area surrounding the steam tubes is flooded with feed (seawater) indicated by the white area in figure 17-3. The steam gives up its heat to the feed and then condenses in the tubes. The condensate that forms in the tubes is continuously being removed by the tube nest drain pump. A portion of this condensate is used to desuperheat incoming steam as described earlier, and the rest is sent to the freshwater drain collecting tank or the main or auxiliary condenser. A drain regulator controls the discharge of the pump to maintain a water seal in the first-effect tubes. This prevents the steam from "blowing through" the tubes without condensing. As the surrounding feedwater absorbs latent heat from the steam, the steam condenses and the water boils.

Vapor Circuit

Some of the feed surrounding the tubes in the first effect will boil into vapor. The vapor, indicated by the light green area in the first-effect shell, passes up into the first-effect vapor separator via baffles. Located near the surface of the feedwater, these baffles trap some of the entrained moisture from the vapor near the feedwater surface. The vapor separator removes the rest. The vapor separator contains a series of baffles or vanes which cause the vapor to change its direction of flow often and rapidly. Centrifugal force (caused by the steam changing directions) forces moisture droplets out of the vapor and onto the sides of the separator where the moisture collects and drains back down into the feed section of the first effect.

The clean moisture-free vapor passes into the vapor feed heater. The vapor feed heater and vapor separator can also be seen in figure 17-2. In this section, incoming feedwater (flowing through tubes) is preheated by the first-effect vapor (surrounding the tubes). Some of the vapor will condense in this process.

The vapor leaves the vapor feed heater through the line labeled 2ND EFFECT EVAPORATOR STEAM and passes into the tube nest of the second effect. As you can see, vapor from the first effect is used as heating steam for the second effect. The shell pressure of the second effect is a vacuum of approximately 26 in. Hg. This lower pressure allows the use of the first-effect vapor to heat and boil the feedwater in the second effect. According to table 17-1, at a pressure of 26 in. Hg, the boiling point of water is approximately 125°F (52°C). As it passes through the second-effect tube nest, the vapor from the first effect is condensed into distillate.

Vapor produced in the shell of the second effect passes through baffles into the second-effect vapor separator and on into the distilling condenser. In the distilling condenser, the second-effect vapor condenses into distillate as latent heat in the vapor is removed by circulating seawater and evaporator feed. (This also preheats the feed.) Distillate from the distilling condenser leaves via the red line labeled DISTILLATE FROM DISTILLER and is piped into the flash chamber. Distillate in the second-effect tubes (which was first-effect vapor) is also piped, via a drain regulator, into the flash chamber. The drain regulator maintains a water seal between the second-effect tube nest and the shell. The flash chamber has a line (green) labeled FLASH VAPOR TO DISTILLER which passes any flash vapors that may form from the hot distillate back to the distilling condenser. The vapors are vented to the condenser and and recooled into distillate.

Distillate Circuit

Distillate that collects in the flash chamber is pumped by the distillate pump through a distillate cooler (red line) and to the test tank. From the test tank, the distillate is directed by a valve manifold (not shown) to either the potable water system or reserve feedwater tanks by the freshwater pump. If the water in the test tanks is contaminated with chloride, it can be sent to the bilge.

Seawater and Feed Circuits

Locate the sea chest (blue) at the lower right of the figure. Seawater is brought in by the distilling condenser circulating water pump from the sea chest and strainer. The water is pumped through the distillate cooler into the distilling condenser (blue line) and overboard through a spring-loaded backpressure regulating valve. A backpressure regulating valve provides a 5 psi backpressure on the circulating water. This valve sets the pressure head required for the evaporator feed (blue-striped line) which is tapped off the circulating water line as it leaves the distilling condenser. The evaporator feed passes through the feed heater section of the distilling condenser, through the tubes of the air ejector condenser, the vapor feed heater, and into the bottom of the shell of the first effect. Leaving the first effect, feed passes through a loop seal and manual regulating valve, into the bottom of the second-effect shell. The direction of flow from the first effect to the second effect is due to the pressure difference between the two effects. (1st effect - 16 in. Hg, 2nd effect - 26 in. Hg).

Brine Circuit

Brine is removed (orange line) from the evaporator by the brine overboard pump. The pump takes suction from the bottom of the second-effect shell and discharges the brine overboard. Gland sealing water for the brine pump is provided by the circulating water system.

Air Ejector Circuit

A two-stage air ejector unit (black-striped line) is located at the top of the plant. The air ejectors remove air and noncondensable gases such as carbon dioxide (CO_2) from the evaporator which helps to maintain the high vacuum in the shell of the second effect. The vacuum in the first-effect shell is established and maintained by the condensation of steam in the vapor feed heater. Steam discharged from the air ejector is condensed by the evaporator feed. The resulting condensate is returned (yellow line) to the ship's feed system through the freshwater drain collecting system.

Salinity Monitoring and Indicating

Electrical salinity cells are provided in the evaporator system to electrically monitor the purity of the water at various points. Salinity cells are strategically located at: (1) discharge of the tube nest drain pump; (2) air ejector drains; (3) distillate out of the distilling condenser; (4) second-effect steam drains; and (5) the distillate pump discharge. The salinity cells are valved into the pipelines at these points to be in contact with the flow of water.

This distillation process is similar for all submerged tube plants, whether they are two-shell double-effect or triple-effect. Figure 17-4 is an illustration of a triple-effect submerged tube distilling plant. As a rule, submerged tube distilling plants are very large compared to other plant types of the same capacity and they have problems with scale formation on the steam tubes. For these reasons, primarily, the submerged tube plants are being phased out for naval use.

OPERATION OF A SUBMERGED TUBE DISTILLING PLANT

Careful starting, operating, and securing of distilling plants will, to a great extent, ensure trouble-free operation. Operating procedures, tests, inspections, and maintenance are discussed in the sections which follow.

Starting a Manually Controlled Plant

To start a low-pressure, submerged tube distilling plant when the evaporators are empty and all pumps are secured, proceed as follows:

1. Open all valves and air vents in the circulating water circuit from the sea suction to the overboard discharge, and start the distilling condenser circulating water pump.

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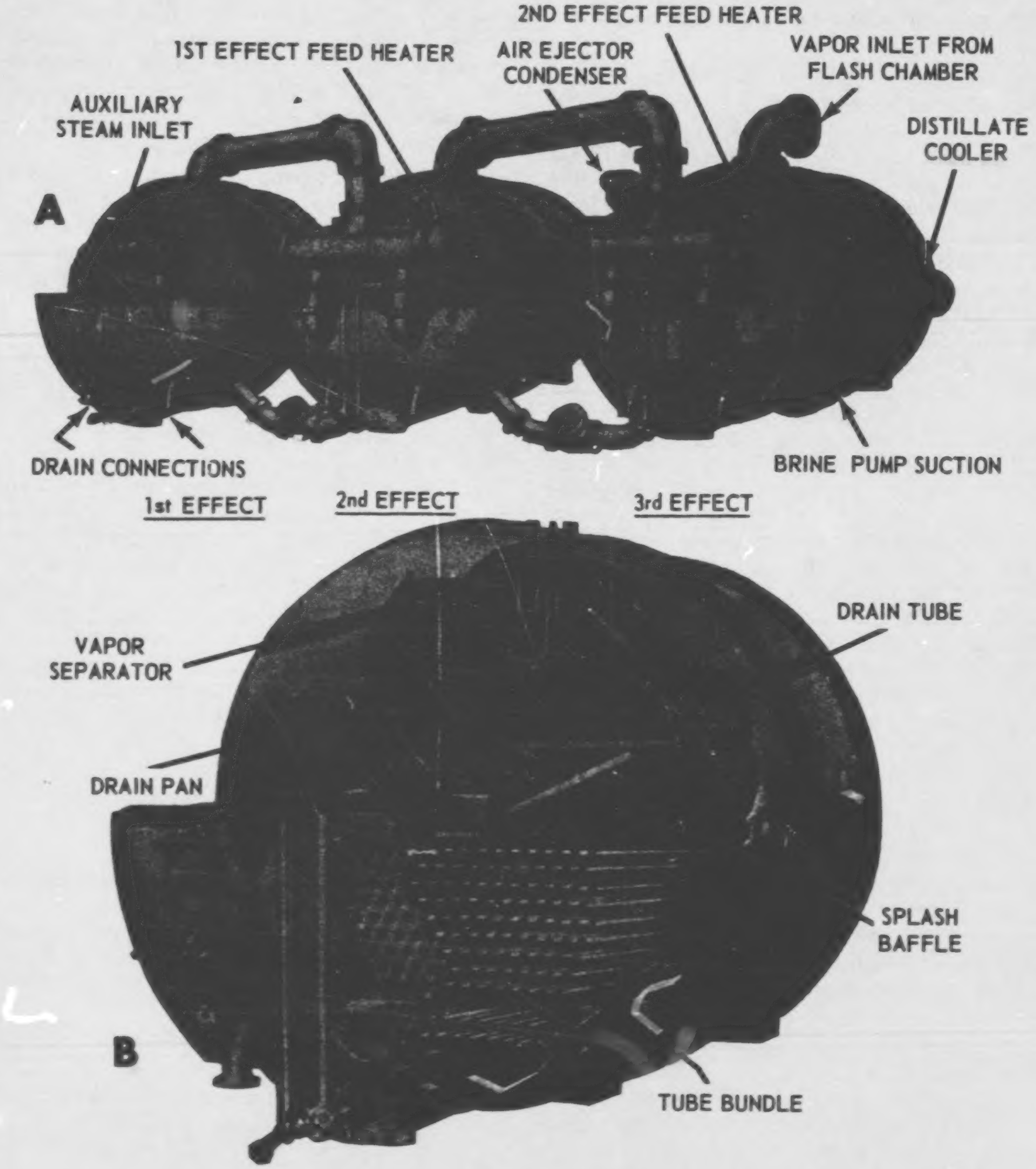
2ND EFFECT FEED HEATER
1ST EFFECT FEED HEATER
AIR EJECTOR CONDENSER
VAPOR INLET FROM FLASH CHAMBER
AUXILIARY STEAM INLET
DISTILLATE COOLER
A
DRAIN CONNECTIONS
BRINE PUMP SUCTION
1st EFFECT
2nd EFFECT
3rd EFFECT
DRAIN TUBE
VAPOR SEPARATOR
DRAIN PAN
SPLASH BAFFLE
B
TUBE BUNDLE

47.118

Figure 17-4.—Triple-effect distilling plant. A. Outside arrangement. B. Internal arrangement of the first-effect shell.

2. Adjust the spring-loaded, back-pressure valve in the circulating water overboard line to maintain a pressure of 5 psig on the feed pump suction.

3. Open all valves in the evaporator feed system and the brine overboard line, except the brine overboard pump discharge valve and the air ejector condenser emergency circulating water overboard valve.

4. Start the evaporator feed pump.

5. When a water level of 10 to 13 inches appears in the second-effect shell, start the brine overboard pump, and crack open the discharge valve on this pump. The brine overboard valve at the ship's side and the valve in the suction to this pump should always be wide open during operation.

6. Open the valve in the emergency circulating water line from the air ejector condenser. Open the second-effect tube-nest vent valve wide; the first-effect tube-nest vent valve remains closed. Open the air ejector suction valve, then open the steam supply to the air ejector; be sure that the full pressure required is available at the nozzle and that the steam supply line is drained.

7. When the second-effect evaporator shell indicates about 16 inches of vacuum, partially open the first-effect steam valve. When distillate appears in the first-effect drain regulator, drain off some of the distillate and test it chemically. If the distillate is salty, discharge it to the bilge until the salinity drops to 0.25 grains per gallon (gpg). If the distillate is acceptable, start the first-effect tube-nest drain pump and discharge to the deaerating feed tank.

8. When a distillate level appears in the second-effect drain regulator gage glass, open the discharge valve at the drain regulator and when distillate appears in the flash chamber gage glass, open the valve at the distillate pump suction.

9. Start the distillate pump and open all valves in the discharge line from this pump to the test tank. When water appears in the gage glass of the test tank, draw off some of the distillate and test it. If the distillate is not of sufficient purity, discharge to the bilges.

10. Open all the required valves in the freshwater system, except the freshwater pump discharge. Start the freshwater pump and regulate the discharge valve to maintain a desired level in the test tank. Open the water meter cutout valves, and close the bypass valves around the water meter so production can be recorded.

11. As the output of the plant is gradually increased, adjust the feed valves to the desired position. When sufficient feedwater is flowing through the air ejector condenser, close off the emergency circulating water valve. Adjust the valves in all vent lines to their normal operating position. When the first-effect steam pressure and the second-effect vacuum both have attained their desired values, check the density of the brine overboard pump discharge. Carefully manipulate the brine overboard control valve until the brine density reaches a value of 1.5 thirty-seconds.

12. If the flow of evaporator feed through the air ejector condenser is stopped temporarily, such as when correcting high feed level in the first-effect evaporator shell, vapor may discharge into the evaporator room through the air ejector condenser vent pipe. To remedy this condition, slightly open the valve in the overboard line from the feed outlet of the condenser to permit water to circulate through the aftercondenser and overboard. Do NOT open this valve more than is required to prevent an excessive amount of heated feedwater being discharged overboard. When, for any reason, the salinity indicator indicates higher than 0.25 gpg (0.065 epm), immediately shift the distillate to the bilges.

Securing a Manually Controlled Plant

The correct procedure for securing a manually controlled low-pressure distilling plant begins by notifying the engineer officer of the watch that the evaporator plant is ready to be secured. When permission to secure has been received, proceed as follows:

1. Secure exhaust steam to the first-effect tube nest and the discharge from the first-effect tube-nest drain pump to the ship's condensate system. Open drain to the bilges.

2. Secure the tube-nest drain pump.

3. Secure the distillate pump.

4. Secure the freshwater pump.

5. Secure the inlet and discharge valves to the freshwater meter.

6. Secure the steam to the air ejector.

7. Close the first-effect tube-nest vent valve.

8. Allow the distilling condenser circulating water pump, evaporator feed pump, and brine overboard pump to continue operating for a few minutes to cool the distilling plant.

9. Secure the brine overboard pump.

10. Secure all pumps, suction and discharge, making sure that evaporator tube bundles are fully covered with water.

11. Close the sea injection valve and the brine overboard valve at the ship's side.

12. Secure the inlet and outlet valves of the second-effect tube-nest drain regulator.

13. Secure the feed valves for each evaporator.

Starting an Automatically Controlled Plant

To start an automatically controlled low-pressure distilling plant when the evaporators are empty and all pumps have been secured, proceed as follows:

1. Open wide all valves in the circulating water circuit from the sea suction to the overboard discharge.

2. Start the circulating pump. Pumps must not be run dry. Before starting any pump, make certain that the suction, vent, and gland seal valves (where provided) are open, and that the pump casing is full of water. On centrifugal pumps, it is preferable to leave the discharge valve closed until after the pump has been started.

3. Check to see that the spring-loaded back-pressure valve is properly adjusted to maintain 5 psi in the discharge line from the distilling condenser.

4. Open all air vent cocks on the distilling condenser, vapor feed heater, and air ejector condenser heads until the air is expelled, then close the vent cocks.

5. If evaporator bundles are submerged, be sure that the first-effect feed valve is closed and that the overflow weir pipes are set at their highest position. If the bundles are not submerged, see that the weirs are at their highest position, open the feed valves until the tube nests are fully covered, and then close the feed valves.

6. Open the valve in the emergency circulating water line from the air ejector condenser.

7. Open wide the second-effect evaporator tube-nest vent valve. The first-effect tube-nest vent valve should remain closed.

8. See that the first-effect tube nest and the air ejector condenser drains are directed only to the bilge, and not to the ship's tanks.

9. Open the air suction to the ejector. Open the stream supply to the ejector, making sure that the full pressure required (stamped on the nameplate) is available at the nozzle, and that the steam supply is properly drained.

10. Test the salinity of the air ejector condenser drain. When less than 0.25 gpg (0.065 epm), close the bilge drain and open the drain to the tank.

11. When the second-effect shell vacuum is about 16 inches, gradually open wide the first-effect tube-nest steam supply valve. Adjust the regulating valve to maintain a steady pressure of 5 psig. The last-effect shell vacuum should continue to increase to 26 inches or more.

12. When the distillate discharges from the first-effect drain line to the bilge, test for salinity. When satisfactory, close the bilge drain valve, set the drain valves to discharge the distillate to the return system, and open the first-effect tube-nest vent valve one full turn.

13. When distillate appears in the second-effect drainer, see that the drainer discharge valve is open, and then adjust the second-effect tube-nest vent valve to operating position (approximately one turn open).

14. When distillate appears in the flash chamber, be sure the distillate cooler discharge is directed to the bilge by manually tripping the solenoid-actuated valve. Then start the distillate

pump. (The same point applies here as was given in 2, with reference to starting a pump.)

15. Perform the following steps in fairly rapid sequence:

a. Lower the overflow weir pipes to their positions.

b. Start the brine pump and open all valves in its discharge line.

c. If a loop seal of at least 8 feet has been provided in the feed line between effects, open wide the second-effect feed valve. Otherwise open it partially.

d. Close the emergency circulating water overboard line from the air ejector condenser and open the first-effect feed valve.

16. When the salinity of the distillate leaving the distillate cooler is less than 0.25 gpg (0.065 epm), set the solenoid valve to discharge to the ship's tanks.

17. Open and adjust the feed-treatment injection valve or pump, if feed treatment is to be done.

18. After the plant has been in operation about half an hour, check the density of the brine. If the density is more than 1.5 thirty-seconds, open wider the first-effect feed valves; if less than 1.5 thirty-seconds, close down on the valve. Repeat every half hour until two successive readings of 1.5 thirty-seconds are obtained. Then test at hourly intervals.

Securing an Automatically Controlled Plant

The correct procedure for securing an automatically controlled low-pressure distilling plant begins by notifying the engineer officer of the watch that the evaporator plant is ready to be secured. When permission to secure has been received, proceed as follows:

1. Shut off the steam supply to the first-effect tube nest.

2. Close the first-effect tube-nest drain line to the return system, and open the drains to the bilge.

3. Close the first-effect tube-nest vent valve.

4. Close the air suction and steam supply valves to the air ejector.

5. Open wide the second-effect tube-nest vent valve.

6. Secure the distillate pump.

7. Raise the weir pipes, on both effects, to their highest positions and continue operation of the circulating water pump and brine overboard pump for 10 minutes or longer to cool off the distilling plants.

8. Secure the brine overboard pump.

9. When both tube nests are fully covered with water, secure the circulating pump.

10. Secure the suction and overboard sea chests.

11. Secure the feed valve to the first effect.

12. Close the air ejector and condenser drain lines to the return system and open the drains to the bilge.

13. Trip the solenoid valve in the distillate lines to discharge to the bilge.

WATCHSTANDING

Proper watchstanding requires the operator to constantly check pressures, temperatures, vacuum, and salinity. Installing automatic controls does not relieve the operator of the responsibility of attentive watchstanding. The most important tests and inspections performed by the EN3 and EN2 standing distilling plant watches are discussed in the section which follows.

Distillate Testing

The freshwater (distillate) produced must meet specified standards of chloride content and purity. To ensure that those standards are met, the distillate must be tested continuously. Chloride content and purity tests are accomplished by two methods: the electrical salinity test and the periodic chemical tests.

The results of distillate tests are expressed in terms of EQUIVALENTS PER MILLION (epm). However, before explaining epm, it will be easier if you understand a unit called PARTS PER MILLION (ppm).

Parts per million is a weight-per-weight unit denoting the number of parts of a specified substance in a million parts of water. For example, 58.5 pounds of salt in 1 million pounds of water represents a concentration of 58.5 parts per million (ppm). Note, also, that 58.5 ounces of salt dissolved in 1 million ounces of water, or 58.5 tons of salt dissolved in 1 million tons of water represent the same concentration—that is, 58.5 ppm.

Equivalents per million—can also be stated as milliequivalent per liter (meq/1)—can be defined as the number of equivalent parts of a substance per million parts of water. (The word "equivalent" here refers to the chemical weight of a substance.) The chemical equivalent weight is different for each element or compound. The chemical equivalent weight of sodium chloride (common table salt) is 58.5. A solution containing 58.5 parts per million of this salt is said to contain 1 equivalent per million. If a substance has a chemical equivalent of 35.5, a solution of that substance containing 35.5 ppm is described as having a concentration of 1 epm.

ELECTRICAL SALINITY TESTING.—Electrical salinity cells (fig. 17-5) are installed throughout the distilling plant to maintain a constant check on the distilled water. An electrical salinity indicator consists of a number of electric salinity cells in various points in the plant—in the freshwater pump discharge, distillate pump discharge, tube-nest drain, and air ejector condenser drain—connected to a salinity indicator panel on a bulkhead near the plant.

Since the electrical resistance of a solution varies according to the amount of ionized salts in solution, it is possible to measure salinity by measuring the electrical resistance. The salinity indicator panel (fig. 17-6) has an ammeter calibrated to read directly in either epm or grains per gallon (gpg). Since resistance also varies with temperature, a temperature-compensator must be set at a value corresponding to the temperature of the solution.

When reading the dial of an electrical salinity indicator, be sure that you know what you are reading. Some salinity indicators are still calibrated in grains of sea salt per gallon. This unit is no longer used for reporting water analyses, so any reading taken in gpg must be converted to epm. Multiply the gpg (meter reading) by 0.261 to get the epm. For example, a meter reading of 0.75 grains of sea salt per gallon is equal to 0.75 X 0.261, or 0.196 epm.

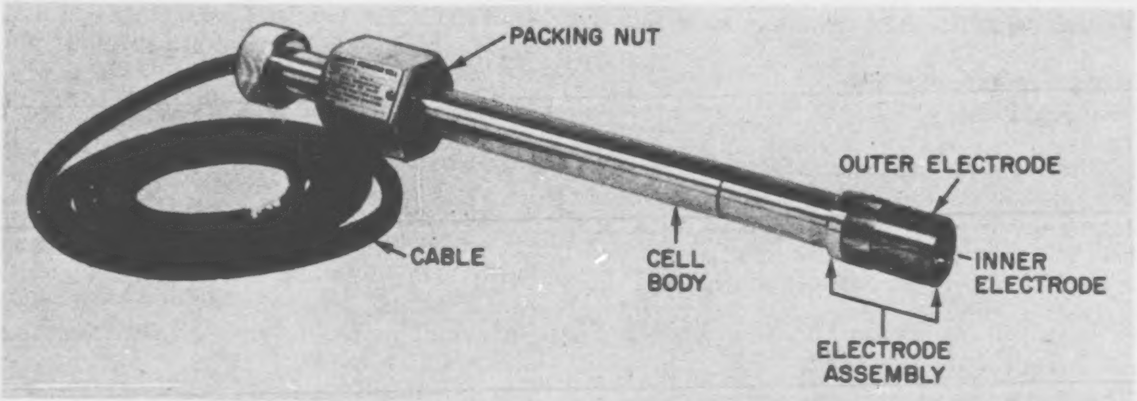

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Figure 17-5.—Salinity indicator cell.

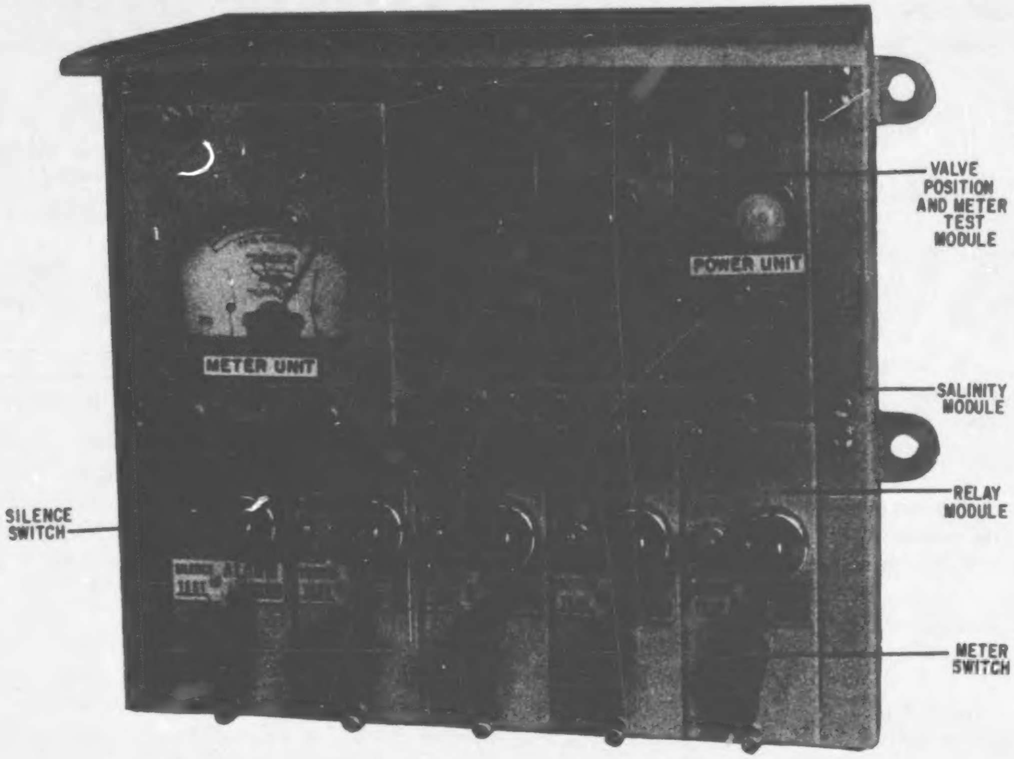

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Figure 17-6.—Salinity indicator panel.

To check an electrical salinity indicator for operation, proceed as follows:

1. Turn on the power to the indicator.

2. Set the temperature-compensator at 110°F.

3. Depress the test button and hold it down until you have taken the reading.

4. Read the indicator. The reading should be approximately 1 grain. If the salinity indicator does not give a reading of 1 grain, the instrument is not correctly calibrated and should be checked by an IC Electrician.

CHEMICAL SALINITY TESTING.–A chemical salinity testing procedure must also be followed for every 50 gallons of distillate pumped into the measuring and testing tanks of the plant. This test is applied to samples of water drawn out through the test cocks of the tanks. Specific instructions for making the tests are generally posted on or near the water testing equipment cabinet provided in each evaporator space. Detailed instructions may also be found in chapter 220-18.25 of the *Naval Ships' Technical Manual*. The general procedure is as follows:

Fill the 100-ml graduated cylinder with a distillate sample from the test tank and pour it into a clean, dry casserole. Add 5 drops of chloride indicator to the sample. (The water should turn blue-violet or red, depending upon its alkalinity.)

Using the nitric acid burette, add reagent nitric acid, one drop at a time, stirring continuously, until the violet or red color just disappears. (The water will probably be pale yellow.) Then, add exactly 1 ml more of reagent nitric acid.

Fill the mercuric nitrate burette and let it drain down to zero. Be sure the tip of the burrette is filled. Then refill the burette.

Place the casserole under the mercuric nitrate burette and add reagent mercuric nitrate to the contents of the casserole. Stir continuously until a pale blue-violet color persists throughout the solution. (Add the mercuric nitrate at a fairly rapid rate at first, but add it very slowly–drop by drop–as the end point is approached.)

Read the burette. Take the reading from the BOTTOM of the MENISCUS (the curved surface of the liquid column). Since the sample size was 100 ml, and the burette factor is 0.25 epm of chloride per milliliter of mercuric nitrate solution, multiply the burette reading by the factor 0.25. For example, if the 100 ml-water sample requires 1.75 ml of mercuric nitrate, the chloride concentration is 1.75 X 0.25, or 0.44 epm.

TEST PERIODS AND CHLORIDE LIMITS.–Chloride content can be determined either with the electrical salinity indicator or by the chemical method. Electrical salinity indicator readings should be checked frequently by the chemical method. Test periods and chloride limits for the various feedwater constituents are as follows:

1. Distilling plant discharge to reserve feed tanks: each measuring tank is to be tested before it is discharged to the reserve feed tanks; the limit is 0.065 epm.
2. Condensate: main condensers, every 15 minutes while underway and every 30 minutes while standing by; auxiliary condensers, every 30 minutes; chloride limit is 0.05 epm.
3. Deaerating feed tanks and surge tanks in use: once each watch; chloride limit is 0.15 epm.
4. Reserve feed tanks: daily and for each tank just prior to being put in use; chloride limit is 0.25 epm.

Test periods and chloride limits are listed in chapter 220 of *NAVSHIPS' Technical Manual.*

Control Orifice

Capacity control is maintained by an orifice in the steam supply line. The orifice controls the flow of steam to the first-effect tube nest. The flow of steam into the tubes is kept constant by maintaining a constant pressure (5 psig) above the orifice. This results in a relatively constant distilling plant output. First-effect tube-nest vacuum automatically adjusts itself to provide the temperature difference required to condense the steam as fast as it enters.

Constant capacity is desirable because it provides a uniformly pure product as well as ease in controlling water levels and brine density.

Weight-Loaded Regulating Valve

A weight-loaded regulating valve is installed in the steam supply line to the first-effect evaporator. This valve maintains the inlet steam pressure at approximately 5 psig above the orifice. There is a vent at the top of the valve body to permit free movement of the valve piston. During operation, this vent must be open at all times. In some new ships, the weight-loaded regulating valve is replaced by a diaphragm-operated control valve, actuated by an air pilot.

Feed Levels

The water level in each evaporator shell is controlled by hand-regulated feed valves or by overflow weirs. At the side of each evaporator shell you can check the level in the shell by examining the gage glass or looking through the sight glass. For most efficient evaporator operation, the tube bundles should be barely covered by the boiling brine.

Desuperheating of Steam Supply

If the steam temperature below the orifice is less than 240°F, desuperheating is unnecessary. However, if the steam temperature is between

240°F and 300°F, desuperheating will be required. Desuperheating is accomplished by taking water from the first-effect tube-nest drain pump discharge and discharging it through a nozzle in the steam line between the orifice and the first-effect tube nest. The desuperheating water should never be taken from the distilling plant distillate or the freshwater pump. The entire boiler feed system could be contaminated if the distillate from the distilling plant becomes salty, since the first-effect coil drains are usually discharged into the deaerating feed tank.

The desuperheating water lowers the steam temperature to the temperature corresponding to the pressure in the first-effect tube bundle.

First-Effect Tube-Nest Vacuum

There should be no noticeable change in the first-effect tube-nest vacuum in any one day's operation because of scale deposits on evaporator tubes. When the tubes are clean and the plant is operated at rated capacity, a sudden drop, or failure to obtain 14 to 16 inches of vacuum is due to some other cause which can and must be eliminated. Do not assume, because the distilling plant output is not immediately affected, that the loss of first-effect tube-nest vacuum is not serious. No matter what the condition of the evaporator tubes, the first-effect tube-nest vacuum should be kept as high as possible. Otherwise more scale will form and the plant will have to be operated at higher temperatures. In addition, frequent cleaning will be required to maintain capacity.

Last-Effect Shell Vacuum

In operating the plant, it is necessary to maintain a constant last-effect shell vacuum, because a rapid fluctuation in this vacuum has a strong tendency to cause priming. It is also necessary to maintain the highest vacuum possible at all times to keep scale formation at a minimum and thus maintain capacity production for long periods without cleaning.

Obtaining maximum vacuum depends upon elimination of air leaks, proper operation of air ejectors, sufficient flow of circulating water, and the effectiveness of the heat transfer surfaces in the distilling condensers.

Air Ejectors

Air ejectors require very little attention during distilling plant operation. In a tight plant, only one air ejector is required to maintain a vacuum of at least 26.5 inches at the air ejector suction.

The air ejector operating pressure, stamped on the nameplate, is the minimum pressure required at the nozzle. Allowance must be made for a pressure drop in the line, through the strainer, when the air ejector steam reducing valve is being set. A pressure at the nozzle, slightly higher than the minimum specified, is permissible unless it causes overheating of the air ejector condenser.

A low vacuum may be due to faulty operation of the ejector, but is more often due to air leakage. An unsteady vacuum, however, usually indicates difficulty at the ejector. The most frequent causes are insufficient steam pressure and wet steam. A clogged strainer or nozzle may also be responsible.

Venting Evaporator Tube Nests

Proper venting of evaporator tube nests is very important. During normal operation of a low-pressure plant, all vents leading from the steam heads to the evaporator shell should be open. When all systems of a distilling plant are operating at approximately normal temperatures and pressures, the vent valves should be adjusted so that they are open about one turn. The amount of valve opening may vary from plant to plant; therefore, the actual setting must be determined by operating experience with a particular plant.

Improper venting of the evaporator tube nests may cause either an accumulation of air in the tubes (with a resultant loss of capacity) or an excessive loss of tube nest steam to the distilling condenser (with a loss of efficiency).

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Brine Concentration

Although the salt concentration of seawater is not always the same, the average is generally accepted as being 1 part in 32—that is, 1 pound of dissolved salts is contained in 32 pounds of seawater. As seawater vaporizes in the distilling plant, the proportion of dissolved salts becomes greater in the remaining solution. The brine concentration in the last-effect shell should be kept at 1.5 thirty-seconds—that is, there are 1.5 pounds of dissolved salts in 32 pounds of brine.

The concentration (density) of brine in the evaporator, within limits, has a direct bearing on the quality of the freshwater distilled by the plant. Since the amount (varying) of brine that is discharged overboard affects the operating conditions of the plant, it is desirable to keep the amount of brine discharged and the brine concentration in the last-effect shell as constant as possible. If the brine concentration is too low, there will be a loss in capacity and economy, and it will be difficult to obtain proper feeding. If the brine concentration is too high, there will be an increase in the rate of scaling of the evaporator tubes, and the quality of the distillate may be impaired. The brine concentration depends mainly on the amount of brine pumped overboard and the amount of freshwater being produced. The brine concentration should be checked frequently during each watch (usually at intervals of 1 hour).

The brine density is measured by SALINOMETERS (fig. 17-7), calibrated to read directly in thirty-seconds. The salinometer has four separate scales which indicate the salinity of the brine at four different temperatures—110°F, 115°F, 120°F, and 125°F.

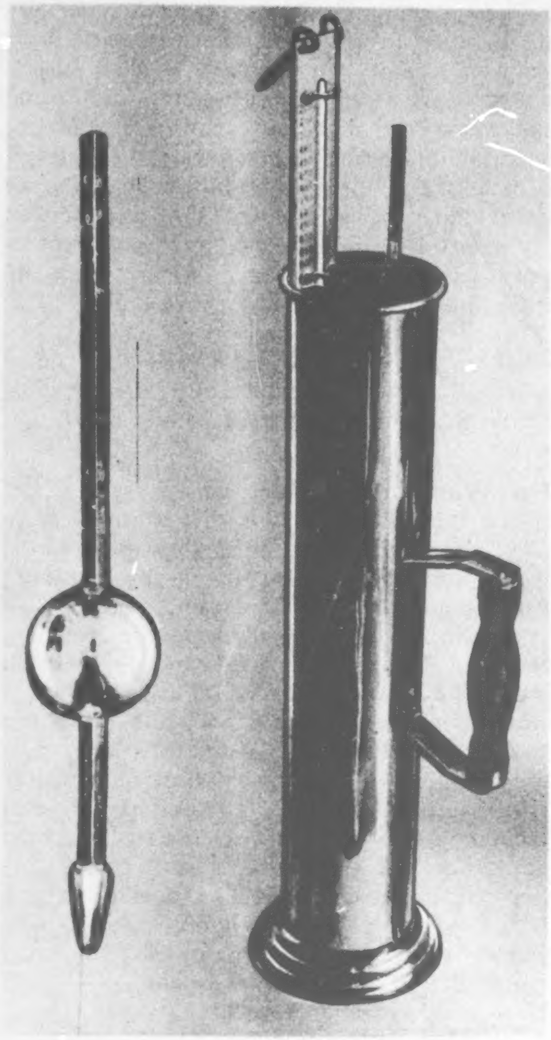

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Figure 17-7.—Salinometer and sampling pot.

Samples of the brine are usually taken from a sampling cock at the brine overboard pump discharge. The sample must be truly representative of the brine in the last-effect shell. The temperature of the sample drawn into the sampling pot should agree closely with the reading of the thermometer on the last-effect shell. A difference of more than 3°F or 4°F usually indicates faulty operation of the brine overboard pump or dilution of the brine between the last-effect shell and the sampling cock.

Operating Record

The Distilling Plant Operating Record is a daily record of the operation of the ship's evaporators and their auxiliaries. Entries are made for each hour of the watch while the distilling plants are in operation. Different ships have different types of distilling plants, but all of the daily distilling plant operating records require practically the same data.

FLASH-TYPE DISTILLING PLANTS

The flash-type distilling plant is widely used throughout the Navy. Flash-type plants have some distinct advantages over the submerged tube type plant. One is that the flash-type "flashes" the feed into vapor (steam) rather than boiling it inside the evaporator shell. The flashing process involves heating the feed before it enters the evaporator shell. The shell is under a relatively high vacuum. The feed is heated to a temperature at which it will flash into vapor when it enters the vacuum. With this design, there are no submerged heat transfer surfaces within the evaporator shell, such as the steam tubes in the submerged tube unit. The elimination of these surfaces greatly reduces the scale formation problem of evaporators and allows prolonged operation at maximum efficiency. Any scale that may form on heat transfer surfaces of a flash-type plant is composed mainly of soft calcium carbonate compounds that are relatively easy to remove.

Two-Stage Flash

Figure 17-8 is an illustration, showing the major components, of the two-stage flash distilling plant that we are going to discuss. Figure 17-9 (foldout #2 at end of chapter) shows the major flowpaths through the two-stage, 12,000 gpd flash distilling plant. Follow along on the diagram during the explanation of the plant which follows.

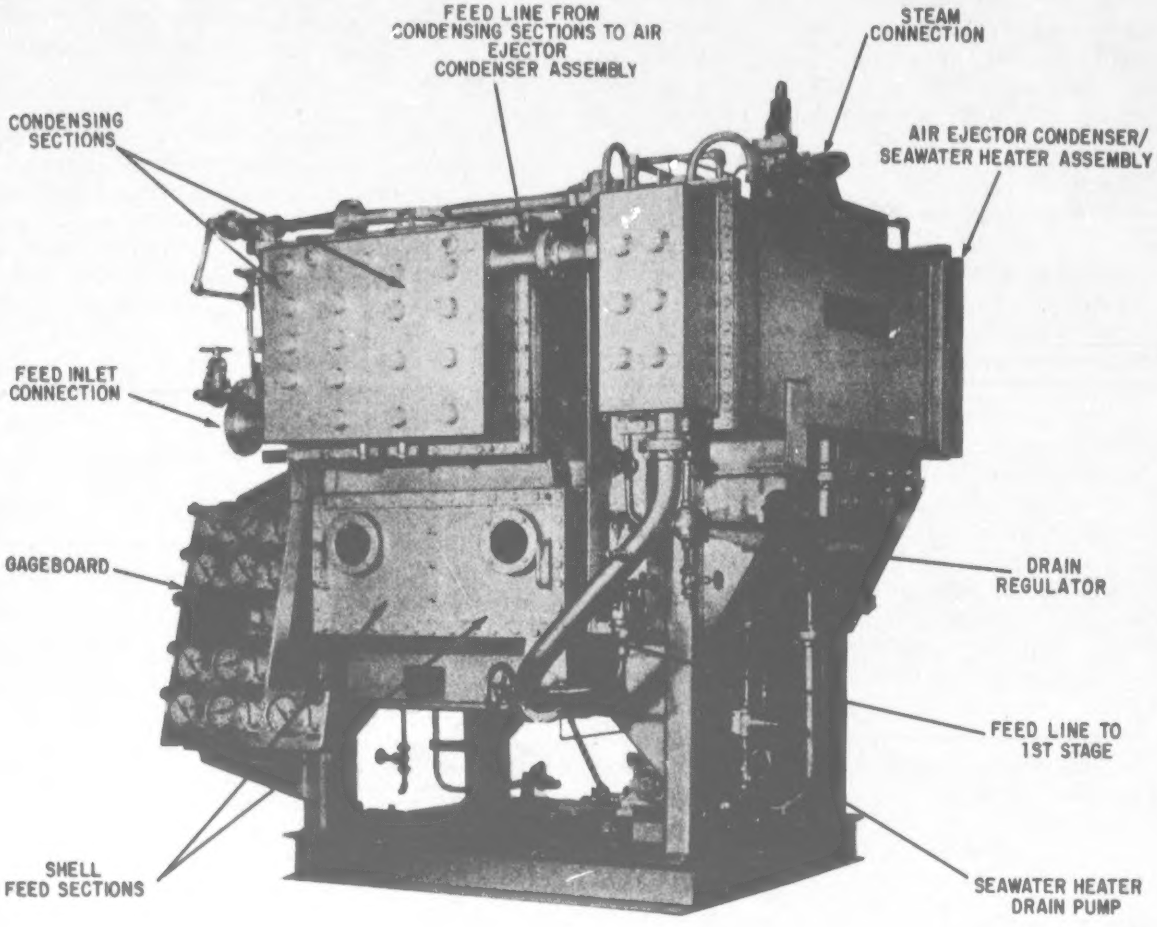
SEAWATER FEED CIRCUIT.–The seawater feed pump (upper left of fig. 17-9) takes a suction through a sea chest and strainer and discharges seawater into the tubes of the condensing section of the second stage of the evaporator. The seawater feed then flows over into the tubes of the first-stage condensing section. The condensing section of the evaporator is a shell and tube heat exchanger which extends the full length of the evaporator shell, i.e., through both the first stage and the second stage.

In the condensing sections, the seawater feed condenses the surrounding vapor and, as a result of the heat exchanger process the feed increases in temperature. When the incoming seawater feed has a temperature of 85°F (29°C), the feed leaving the first-stage condensing section of the evaporator should be approximately 138°F (59°C).

Upon leaving the first-stage condensing section, the feed enters the air ejector condenser/seawater heater assembly. In this double-flow, shell and tube heat exchanger, the feed picks up heat by condensing exhaust steam from the air ejectors and from steam admitted to the seawater heater from the auxiliary exhaust steam system.

The feedwater leaves the air ejector condenser/seawater heater assembly at a temperature of approximately 170°F (77°C) and is fed to the first stage of the evaporator shell. The feed enters the bottom of the shell through two spray pipes, which partially atomize the water, and aids in "flashing" the feed into vapor. Feed that does not flash in the first stage is directed to the second stage through an internal loop seal located at the bottom of the shell. Flow control of the feedwater is accomplished by manual operation of the feed valve in the line just before the first stage.

The feedwater enters the second stage in a manner similar to the way it entered the first-stage shell. The force that moves the feed from the first to the second stage is the pressure differential between the two stages. The first stage shell pressure is maintained at approximately 23 in. Hg while the second-stage shell pressure is approximately 27 in. Hg. Also assisting is the head due to the higher water level in the first stage which overflows into the second stage. This loop seal arrangement prevents the pressure from equalizing between


FEED LINE FROM CONDENSING SECTIONS TO AIR EJECTOR CONDENSER ASSEMBLY
STEAM CONNECTION
CONDENSING SECTIONS
AIR EJECTOR CONDENSER/ SEAWATER HEATER ASSEMBLY
FEED INLET CONNECTION
GAGEBOARD
DRAIN REGULATOR
FEED LINE TO 1ST STAGE
SHELL FEED SECTIONS
SEAWATER HEATER DRAIN PUMP

47.210

Figure 17-8.—2-stage, 12,000 gpd flash-type evaporator.

the stages. Feedwater that does not flash into vapor in the second stage becomes brine which is pumped overboard.

VAPOR CIRCUIT.—Vapor is formed in the first-stage shell by the hot feedwater (170°F [77°C]) as it enters the shell which is "under" a vacuum (23 in. Hg). Saturation temperature for 23 in. Hg is approximately 148°F (64°C). The feed enters the first stage shell through two spray pipes fitted with deflector plates which cause the feed to spray downward and form a thin, circular curtain of water. This partially atomized curtain of spray results in more complete transformation of the water into vapor steam. The vapor then rises through copper-nickel (Monel) mesh-type demisters (moisture separators) which remove entrained moisture from the vapor. (The moisture removed from the vapor drains back into the bottom [feed] section of the evaporator shell). The vapor then passes into the condensing section of the evaporator shell where it is condensed into distillate by the cooling action of the incoming feedwater. Vapor produced in the second stage goes through the same process.

The shell pressure is lower in the second stage, however (27 in. Hg) with a subsequent lowered saturation temperature of approximately 115°F (46°F).

DISTILLATE CIRCUIT.–Distillate is formed in the condensing section of both stages of the evaporator. The distillate from the first stage collects in the bottom of the first-stage condensing section in a hotwell-like area (trough) formed by the joint between the evaporator shell division plate and the first-stage collection tray. The distillate passes through a loop seal into a higher trough (or tray) in the second stage. The piping between the two stages contains an orifice plate with a 5/8-inch diameter orifice which controls the flow rate and prevents equalization of pressure between the stages and, also, prevents premature "flashing" of the distillate as it enters the lower pressure area of the second stage.

The distillate is then pumped out of the second-stage distillate trough by the distillate pump. The distillate pump discharges the water through a three-way solenoid-operated trip valve (fig. 17-10), which, when tripped, will automatically divert the flow of distillate to the bilge if the salinity content reaches a predetermined setpoint (usually 0.065 epm). When the valve is in the reset (normal) position, distillate passing through it goes on through a flowmeter and into an interlocked two-valve manifold. The two-valve manifold directs the distillate to either the potable water system or the reserve feed system. The manifold is interlocked to prevent opening of both valves at the same time. The potable water system can be contaminated with chloride from a shore water source, which may be suitable for drinking but not for boiler feed. The potable water system and the reserve feed system, therefore, should NEVER be cross-connected in any way.

AIR EJECTOR CIRCUIT.–A two-stage air ejector unit, using auxiliary steam is located at the top of the distilling plant. It draws vacuum and assists in maintaining the vacuum in the evaporator shell. The air ejector second stage discharges into the air ejector condenser section of the air ejector condenser/seawater heater assembly. The air ejector condenser condenses the steam and vents air and noncondensables (such as CO_2) to the atmosphere. The condensate, which forms from the steam, drains to either the bilge or the steam drain collecting system through a three-way solenoid-operated trip valve.

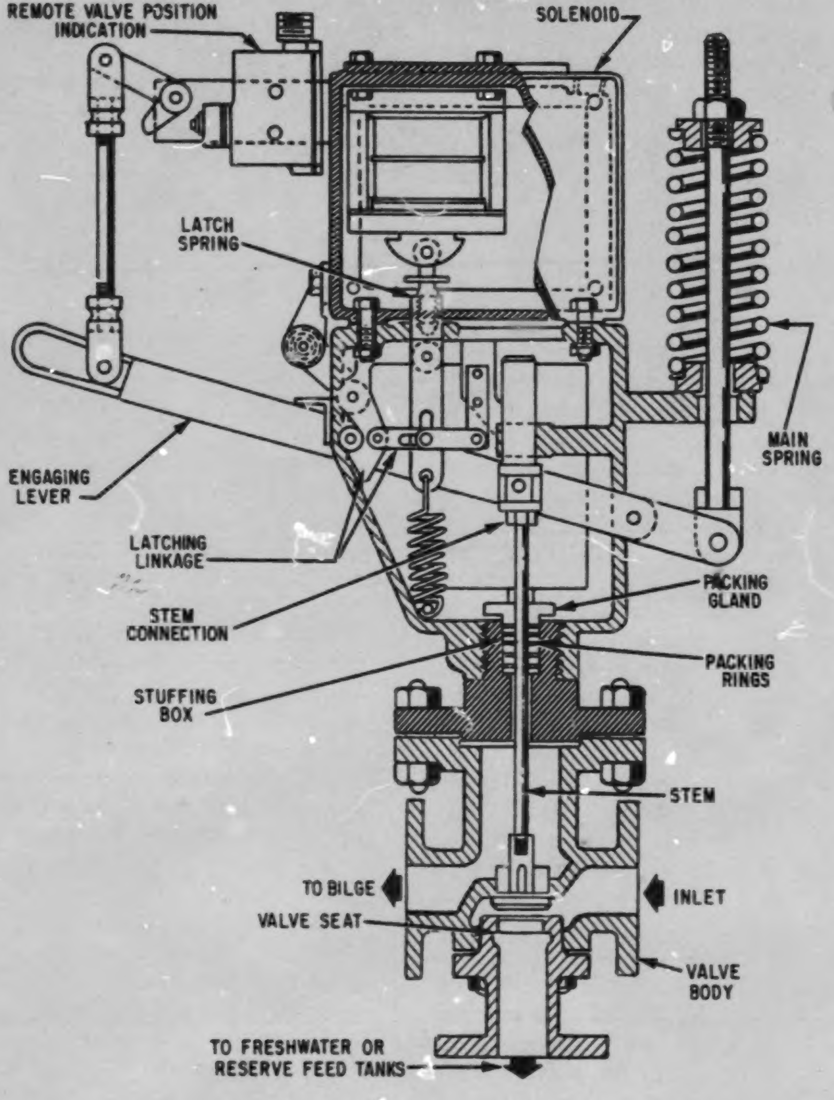
BRINE CIRCUIT.–Brine (dark green) is pumped out from the bottom of the second-stage shell. A centrifugal pump is used for this purpose.

HEATING STEAM CIRCUIT.–Auxiliary exhaust steam is used in the seawater heater to provide the heat required to raise the temperature of the seawater feed to approximately 170°F (77°C). The auxiliary exhaust steam entering the seawater heater passes through an orifice which controls the quantity of the steam admitted to the heater. The steam pressure upstream of the orifice is approximately 3 psig.

The seawater heater is vented to the first-stage evaporator through a line with a 1/4-inch orifice to bring the seawater heater pressure to approximately 9 in. Hg (10 psia). The pressure differential between the auxiliary exhaust steam pressure above the orifice and the seawater heater pressure is critical in providing proper steam flow to the heater. Improper steam flow will cause the distilling plant output to vary.

Before it enters the seawater heater, the auxiliary exhaust steam is desuperheated by water sprayed into the steam inlet piping. The amount of water for desuperheating is adjusted by an automatic control valve to maintain the steam temperature 5° to 10°F higher than seawater heater shell temperature. In this manner the temperature of the seawater feed leaving the air ejector condenser/seawater heater assembly is maintained relatively constant.

The water supply for the desuperheating water is a portion of the discharge from the seawater heater drain pump. During plant startup, when water from the seawater heater drain pump may not be available, the ship's condensate system furnishes the water supply. A two-valve interlock between the supply from the seawater heater drain pump and the supply from the condensate system prevents cross-connecting


REMOTE VALVE POSITION INDICATION
SOLENOID
LATCH SPRING
MAIN SPRING
ENGAGING LEVER
LATCHING LINKAGE
STEM CONNECTION
PACKING GLAND
PACKING RINGS
STUFFING BOX
STEM
TO BILGE
INLET
VALVE SEAT
VALVE BODY
TO FRESHWATER OR RESERVE FEED TANKS

47.214

Figure 17-10.—Three-way solenoid trip valve.

of these two systems. The two-valve interlock is similar to that described for the distillate circuit.

SEAWATER HEATER DRAIN CIRCUIT.—Condensed auxiliary exhaust steam is pumped from the shell of the seawater heater by the seawater heater drain pump. A drain regulator serves as a hotwell and assures a constant suction head for the pump. The drain regulator is a ball float-operated valve attached below the condensate drain connection of the seawater heater. The ball float in the drain regulator operates the valve to maintain a relatively constant water level in the housing, which is indicated by a gage glass. A decrease in water level will tend to close the valve in the drain regulator. Therefore, the amount of condensate discharged by the drain pump will be throttled until the water level in the float housing rises again. The water level in the regulator maintains a suction head for the seawater heater drain pump and prevents loss of vacuum in the seawater heater by maintaining a water seal between the heater and the pump.

The drain pump discharges condensate from the seawater heater to the condensate system (startup only) to the steam drain collecting system (normal lineup) or to the bilge.

SALINITY MONITORING AND INDICATING.–Four salinity cells in the plant provide continuous monitoring of water purity: (1) at the loop seal line between the first- and second-stage distillate; (2) at the distillate pump discharge; (3) at the air ejector drain line; and (4) at the seawater heater drain pump discharge. All of the salinity cells are read on a salinity indicating panel. Two of the cells, located at the distillate pump discharge and the air ejector drains, also control three-way solenoid-operated trip valves which are automatically "tripped" to divert the flow of water to the bilge to prevent contamination of a pure water system.

Other Applications of the Flash-Type Distilling Unit

Flash-type distilling plants may have any number of stages and output capacities. For example, the Navy uses one type of three-stage, 30,000 gpd plant as well as a five-stage, 50,000 gpd unit. All flash-type plants operate on the same basic principles as those described for the two-stage plant.

Operating Notes for Flash-Type Units

The rate of feed to the first-stage inlet box should be maintained constant at all times, provided the plant is producing its normal capacity or less. Distilling plants are designed to operate at a definite number of gallons of feed per minute, which is indicated by rotameters in the feed line between the distilling condenser circulating water pump and the distillate cooler. All other valves in the feed line should be opened wide to prevent their interfering with the proper flow of feed through the plant.

With proper feed flow and with a clean plant, the temperature of the feed entering the first-stage feed inlet box will be 175°F (79°C) or less, depending on the temperature of the seawater. Plants are designed to operate with a feed temperature of 175°F (79°C) maximum when the temperature of the seawater is 85°F (29°C); when the seawater temperature is lower, the feed temperature will be correspondingly lower.

No attempt should be made to control the feedwater temperature after it leaves the feedwater heater and enters the first-stage flash box. The temperature should adjust itself to the varying plant conditions. Full capacity will be realized with proper feed flow, proper vacuums throughout the plant, and proper steam pressure above the orifice.

The feed temperature should never be allowed to exceed 175°F (79°C). Higher operating temperature will greatly increase the amount of scale formation.

Although the capacity of the flash-type distilling plant depends on (1) the quantity of evaporator feedwater entering the first-stage feed box and (2) the difference in temperature between the feedwater entering the first stage and the vapor in succeeding stages, the capacity can be changed only by increasing or decreasing the amount of heat added to the seawater by the feedwater heater.

With a constant steam pressure of 5 psig above the orifice, an increase in the feed flow will decrease the temperature in the first-stage flash chamber, which will also decrease the temperature of the vapor in the succeeding stages, and the capacity will remain constant. Therefore, the capacity of the plant can be changed by changing the steam pressure above the orifice.

VERTICAL BASKET DISTILLING PLANTS

Some of the newer ships have distilling plants that differ somewhat from the submerged tube type. One such type is the vertical basket plant.

The low-pressure vertical-basket type distilling plant (fig. 17-11) consists of two-effect (or more) evaporators with a distiller condenser, vapor feed heaters, air ejectors and aftercondensers, and a distillate cooler. The only difference between this type of distilling plant and the conventional submerged tube type is in the evaporators.

Each evaporator consists of a vertical shell which contains a deeply corrugated vertical basket. (See fig. 17-12.) Some installations may use more than one basket. Low-pressure steam is admitted to the inside of the first-effect basket, and feedwater is boiled in the space between the outside of the basket and the shell. The vapor, formed from the boiling feedwater, passes through centrifugal-type mesh-type vapor separators and the vapor feed heater into the inside of the second-effect basket. This boils the brine from the first-effect in addition to a certain amount of feedwater in the space between the shell and the basket. The vapor thus formed passes through separators to the subsequent effects or, in a two-effect basket, into the distiller condenser.

A schematic diagram of the flow circuits of a vertical basket distilling unit is shown in figure 17-11. Refer to this figure as you study the following description of the flow circuits of the unit.

STEAM FLOW CIRCUIT

Heating steam from the ship's auxiliary exhaust main is fed through a pressure-control valve to the steam chest of the first effect. The pressure-control valve is set to maintain a constant steam-supply pressure; it should be set for 5 psig steam on the upstream side of the orifice plate for rated output, and lower for reduced output. The heating steam is condensed within the corrugated basket; the condensate is returned to the ship's condensate system (boiler) or reserve feed tanks by the first-effect drain pump.

A steady water level is maintained in the suction line of the first-effect drain pump by the drain controller; this ensures a positive submergence head for the pump. If the first-effect drain pump fails, the evaporator can be kept in operation by bypassing the drain controller and manually controlling the condensate discharge to the low-pressure drain mains; at least 1 psig pressure in the steam chest is required, under these conditions, to drain the condensate.

FEED FLOW CIRCUIT

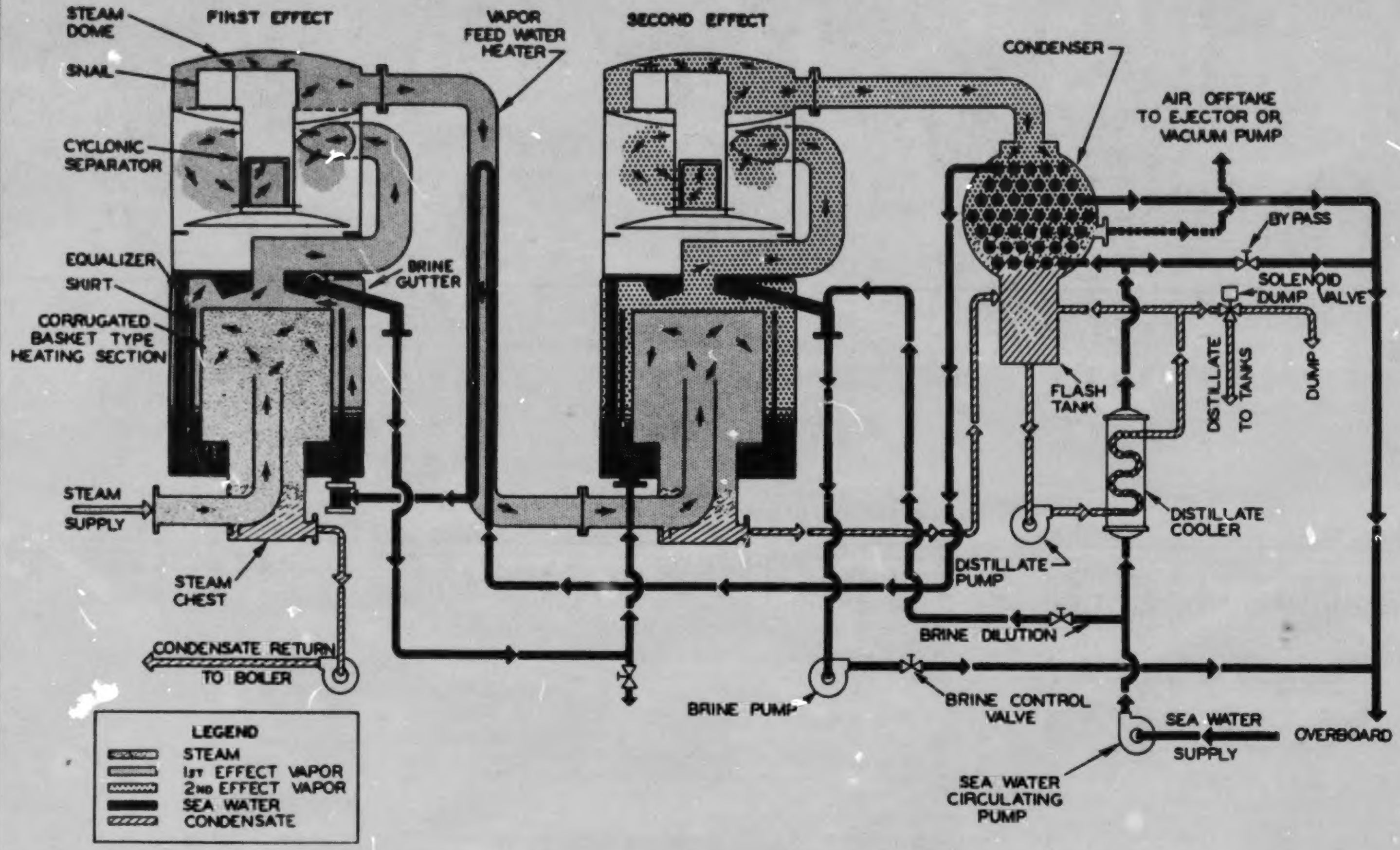
Seawater feed is taken from a sea chest, through a strainer, by the seawater circulating pump, and is discharged through the distillate cooler. (The incoming feed serves to cool the distillate from the distiller condenser to within a few degrees of the temperature of the feed.) The seawater then passes through the distiller condenser; the major portion (about 75%) goes through the eductor, combines with the brine (from the second effect), and is discharged overboard.

The feed remaining in the condenser is directed through the aftercondenser and the vapor feedwater heater to the first effect, where it surrounds the basket. Violent boiling takes place and vapor forms within the first effect. The remaining brine serves as feed for the second effect. (Earlier models were equipped with a branch from the feed line, which led from the heating section of the distiller condenser to a connection on the bottom of the second effect; as a result, the second effect was supplied with brine from the first effect, and heated seawater from the heating section of the distiller condenser as feed.) In current models, all feed enters the first effect.

The brine from the second effect is removed by the brine overboard-discharge pump; it is discharged overboard, through the eductor and control valve, after it has been combined (in the eductor) with the seawater overboard discharge from the distiller condenser.

VAPOR CIRCUIT

The vapor which forms as a result of the boiling of the feed in the first effect passes


STEAM DOME
FIRST EFFECT
VAPOR FEED WATER HEATER
SECOND EFFECT
CONDENSER
SNAIL
AIR OFFTAKE TO EJECTOR OR VACUUM PUMP
CYCLONIC SEPARATOR
BY PASS
EQUALIZER
SKIRT
BRINE GUTTER
SOLENOID DUMP VALVE
CORRUGATED BASKET TYPE HEATING SECTION
DISTILLATE TO TANKS
DUMP
FLASH TANK
STEAM SUPPLY
DISTILLATE COOLER
STEAM CHEST
DISTILLATE PUMP
BRINE DILUTION
CONDENSATE RETURN TO BOILER
BRINE PUMP
BRINE CONTROL VALVE
SEA WATER SUPPLY
OVERBOARD
SEA WATER CIRCULATING PUMP
LEGEND
STEAM
1ST EFFECT VAPOR
2ND EFFECT VAPOR
SEA WATER
CONDENSATE

47.126

Figure 17-11.—Low pressure double-effect distilling plant (vertical basket type).

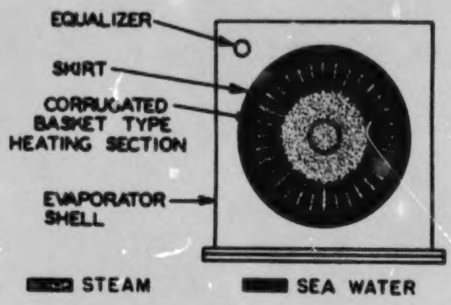


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Figure 17-12.—Section view of evaporator (vertical basket type).

through the uptake pipe and enters the cyclonic separator above the evaporation section. Most liquid particles which carry over with the vapor are removed by centrifugal force within the first-effect separator. The first-effect vapor passes from the steam dome, through the vapor feedwater heater, to the steam chest and the evaporator basket of the second effect. Some of the vapor, in passing from the first effect to the second effect, condenses as it heats the feedwater passing through the vapor feedwater heater. The major portion of the first-effect vapor, however, enters the second-effect steam chest and condenses as it heats the brine in the second effect.

The vapor resulting from the boiling of the brine in the second effect passes through the second-effect uptake into the second-effect separator, where centrifugal force removes water particles from the second-effect vapor. (Liquid particles from both stages drain downward and become part of the brine drains.) This two-stage separation results in distillate with less than 0.065 epm chloride under normal operating conditions. From the second-stage separator, the vapor passes, through the steam dome, to the distiller condenser, where the vapor is condensed as it is cooled by the incoming feed.

DISTILLATE CIRCUIT

The condensate formed in the second-effect steam chest passes, through a loop seal, to the flash tank of the distiller condenser, under the pressure differential existing between the second-effect steam chest and the flash tank. The loop seal permits only condensate to pass.

The vapor from the second-effect steam dome condenses in the distiller condenser and collects in the flash tank at the bottom of the distiller condenser. The distillate (combined condensate drains from the distiller condenser and the second-effect steam chest) is removed from the flash tank by the distillate pump and is discharged through the distillate cooler and the solenoid-operated dump valve to the ship's service tanks.

In some vertical basket units, the discharge rate of the distillate pump is controlled automatically by a drain controller. The drain controller maintains a positive water level in the flash tank so that the pump will not become vapor-bound. Later models of vertical basket units have a recirculating line to the flash tank instead of a drain controller. A throttle valve is included in the recirculating line. The recirculating line supplies relatively cold freshwater to the flash tank. The cooling water reduces the temperature of the distillate below the flashpoint; thus, vapor lock within the distillate pump is prevented. The recirculating line also ensures, through control of the throttle valve, a positive suction head on the distillate pump.

Under normal operating conditions, the vertical basket distilling unit produces distillate with less than 0.065 epm chloride (0.25 grains salt per gallon). If the unit is to produce relatively pure distillate, saltwater must be prevented from entering the vapor and condensate systems. A salinity cell in each of the unit's freshwater lines prevents saltwater contamination of the ship's freshwater supply. If a saltwater leak should develop in the distillate circuit, the salinity indicator actuates the solenoid dump valve, which diverts the contaminated water to the bilge until the unit can be secured and the leakage can be stopped.

NONCONDENSABLE GASES

An air ejector removes air and other noncondensable vapors in the distiller condenser and maintains a vacuum throughout the evaporator units. The ejector is a single-nozzle, single-stage, steam jet type. The ejector is mounted on the side of the distiller condenser and takes its suction from a specially baffled section within the distiller condenser. Vent lines and interconnecting vapor-piping connect components in which vacuum must be maintained.

The air ejector removes the air and other noncondensable vapors from the distiller condenser by using the energy in steam at 150 psi. The gases entering the suction of the ejector are entrained by the steam jet from the nozzle and are carried through the diffuser, where the pressure is raised to that of the atmosphere. The ejector discharges into a surface aftercondenser, where the steam is condensed and the noncondensable gases are vented to the atmosphere.

HEAT RECOVERY TYPE DISTILLING UNITS

Heat recovery type units are used in some vessels with engine propulsion or auxiliary engines. Two variations of the heat recovery types are used; both use the heat from engine cooling systems for evaporization of seawater.

In one model of a heat recovery plant, the heat of the diesel engine jacket water is transferred to the seawater in a heat exchanger. The heated seawater is then "flashed" to freshwater vapor as in the flash-type distilling unit. In the second variation, the diesel engine jacket water is circulated through a tube bundle which is submerged in seawater. The seawater is boiled in a chamber which is under vacuum as in the submerged tube type distilling unit.

A simplified flow diagram for a 12,000 gpd, Model S500ST submerged tube recovery unit, is shown in figure 17-13. In this recovery unit, jacket water from the ship's main propulsion diesels is fed to a tube bundle. The tube bundle is submerged in the seawater which is to be evaporated. The jacket water imparts its heat to the seawater surrounding the tubes, thereby inducing evaporation of the seawater. The vapor created by the evaporating seawater is drawn through vapor separators to the distillate condensing tube bundle. The temperature of evaporation is maintained below the normal 212°F boiling point by a feedwater operated air eductor. This eductor mechanically evacuates air and gases entrained in the vapor formed in the evaporating process and creates an internal shell pressure as low as 2 1/2 psia.

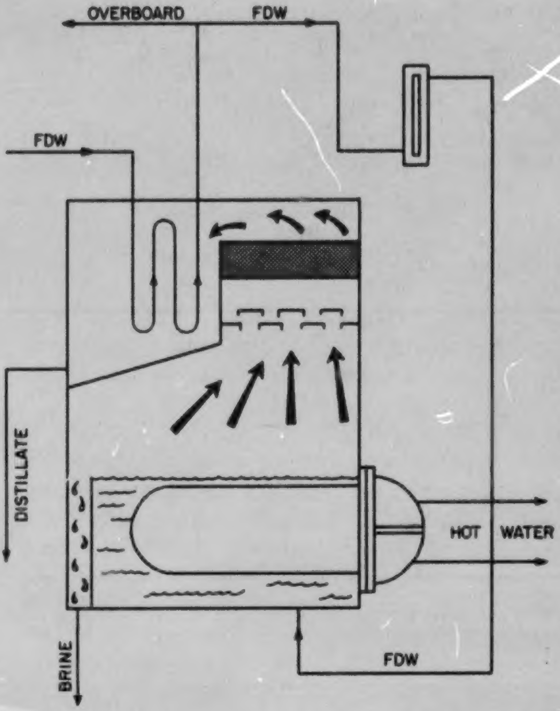

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Figure 17-13.—Simplified flow diagram—heat recovery unit.

SEAWATER CIRCUIT

Seawater is pumped into the unit by the saltwater circulating pump and enters at the distillate cooler. It is then channeled through the condenser tube bundle, after which the greater portion of the flow is used in operating both the air eductor and the brine eductor, before being discharged overboard. The remaining smaller portion then transverses the condenser tube bundle. From this tube bundle, it enters the bottom of the evaporator. Feedwater level within the shell is controlled by an internal weir-type controller. Unevaporated feedwater, now referred to as brine, is discharged from the shell, drawn off by the brine eductor, and forced overboard.

DISTILLATE CIRCUIT

Generated vapor, which if produced at temperatures much below normal atmospheric boiling point, rises to the upper section of the shell and passes through a vapor separator. The separator, which consists of woven beds of Monel wire, causes the vapor to change its direction of motion many times as it passes through the bed. This highly active motion, at a considerable velocity, has the mechanical effect of separating moisture from the vapor and thereby produces a dry saturated steam which, when it condenses, assures a pure distillate. Separated moisture, which may contain salt particles, drips back to the feedwater. Separated vapor continues its flow to the distillate condensing section. The vapor is condensed and its latent heat is absorbed by the feedwater passing through the tubes. The resultant distillate is then drawn off by the action of the distillate pump and circulated through the shell side of the sterilizer/drain cooler, which heats the distillate to destroy possible contaminants. Steam, used as the heating medium, is condensed in the process and the drains are cooled before leaving the sterilizer/drain cooler. Sterilized distillate then circulates to the potable point. There a three-way solenoid valve discharges the distillate to storage or to waste, depending upon its purity. The solenoid valve receives its signal from a monitoring salinity cell in the distillate cooler discharge line. If the present purity level is exceeded, the salinity equipment automatically induces a dumping action in the solenoid valve. Pure distillate is metered for the quantity stored.

AIR REMOVAL CIRCUIT

Air and noncondensable vapors enter the evaporating plant mainly with feedwater in which they are dissolved. These gases are released into the vapor space of the unit, as the water evaporates, and collect in all parts of the plant. Air also enters through various small leakage points such as pump glands and imperfect vacuum joints. The distillate condenser, which is at the lower end of the heat flow cycle, is the collecting point for most of these gases because of lower pressures existing in that area. Collection of these gases hinders efficient heat transfer because of the insulating blanketing effect on the tubes. To maintain high vacuum and efficient heat transfer in the plant, the noncondensing gases are extracted and expelled to the atmosphere by an air eductor. Feedwater, issuing from a nozzle inside the eductor, creates a vacuum and entrains the gases, compresses them to a pressure slightly above atmospheric pressure, and expels them overboard.

JACKET WATER CIRCUIT

The unit has been designed to operate using jacket water from the main propulsion diesels. The jacket water makes a four-pass flow through the tube bundle. The first pass is through the upper layers of tubes and accomplishes the greater part of the evaporation. The jacket water circuit provides a waterflow of 300 gpm at a temperature of 180°F to the tube bundle. However, when the diesel engines will not provide sufficient heat, a steam heater and electric heater are used.

The steam heater, in conjunction with the electric heater, heats the water circulating through the tube bundle during at-anchor operation. Jacket water passes through the tubes of the heater while steam is admitted to the shell side of the heater raising the temperature of the circulating water to 167°F. The water is then directed through the electric heater to raise the temperature to 180°F before it is admitted to the heating tube bundle. A hot water circulating pump provides motive force for the jacket water during at-anchor operation. The electric heater is also located in the jacket water piping and is used with the steam heater as a supplementary heater during main propulsion diesel warmup and during at-anchor operation. The jacket water, after passing through the steam heater, passes through the shell side of the electric heater.

AIR AND BRINE EDUCTORS

Air and brine eductors, mounted externally to the evaporator shell, are both feedwater operated. The air eductor provides the initial vacuum necessary for unit startup. Once the unit is in operation, however, its primary function is to remove noncondensables from the shell interior. These noncondensables are then directed overboard. The brine eductor removes unevaporated brine from the shell interior after it passes over the brine duct. The unevaporated brine is then also directed overboard. The basic components of each eductor are a Monel feedwater nozzle and cast bronze feedwater chest. The nozzle increases the velocity of feedwater entering the feedwater chest which, in the case of the air eductor, produces the vacuum which withdraws noncondensables from the evaporator, and which, in the case of the brine eductor, produces a vacuum which withdraws nonevaporated brine.

MAINTENANCE OF LOW-PRESSURE DISTILLING PLANTS

The full output of a distilling plant can be maintained for relatively long periods without interruption only if every part of the plant is kept in proper operating condition. This can be accomplished by periodic tests, inspections, cleaning, and maintenance. No strict schedule can be set up, but experience with a particular installation may indicate the frequency of testing, inspecting, cleaning, and maintenance required for the unit. The following are some of these maintenance procedures and the approximate frequency required.

CARE OF HEAT EXCHANGER SURFACES

The output of the low-pressure, submerged tube distilling plant is not reduced appreciably by scale deposits on the evaporator tubes until the deposits have caused a reduction in first-effect tube-nest vacuum to 1 or 2 inches of mercury. When the first-effect tube nest vacuum is lost entirely the reduction in output becomes very great. Assuming the reduction in vacuum is due to scale and not the result of improper operating conditions, the evaporator tubes MUST be cleaned when the tube-nest vacuum approaches zero. To maintain adequate output the tubes SHOULD be cleaned when the first-effect tube-nest vacuum falls below 3 inches of mercury.

When the plant is properly operated and when the evaporator feed is treated, the interval between cleanings should be 6 months or more.

Saltwater flows inside the distilling condenser tubes, air ejector condenser, and vapor feed heaters. Under some operating conditions, scale deposits may accumulate inside these tubes, particularly in the air ejector condenser and the first-effect feed heater. Every 6 months, or whenever the plant is secured for descaling evaporator tubes, the inside surfaces of these heat exchanger tubes should be inspected and cleaned if necessary. Neglect can lead to thick scale deposits which will be difficult to remove.

Scale Prevention

Very little hard scale should form in a distilling plant that uses seawater for feed if feedwater distribution is proper, if steam pressure above the orifice is not more than 5 psi, if a high vacuum is maintained, and if the density of the brine overboard is not over 1.5 thirty-seconds.

During normal operating conditions, scale deposits will form at a certain rate on the distilling plant evaporator tubes. The rate of scaling depends upon the concentration of suspended matter and carbonates present in the seawater or freshwater used to feed the distilling plant. However, the important point to remember is that excessive scaling of the evaporator tubes can be caused by improper operation of the distilling plant.

The scale deposits increase as the density of the brine increases in the last-effect shell. The brine concentration is dependent mainly upon the quantity of brine pumped overboard and upon the amount of freshwater produced. If the brine concentration is too high, the rate of scaling of the evaporator tubes will increase, and the quality of the distillate may be impaired.

To retard the formation of scale on evaporator tubes and to minimize priming, solutions are continuously injected into the evaporators.

A chemical compound known as PD-8, formerly called Hagevap, replaces cornstarch and boiler compound for the treatment of evaporator feedwater and has been accepted as the Navy STANDARD FEED TREATMENT COMPOUND. PD-8 has proved to be superior because of its ability to prevent the formation of scale. PD-8 increases the production of distilled water by decreasing the amount of time that plants must be shut down for cold shocking and scale removal.

PD-8 is composed of polyphosphates, lignins, and antifoam agents. The polyphosphates combine with the scale-forming particles in seawater, while the lignins keep the resulting solids dispersed and suspended. The antifoaming agents prevent foaming and help prevent scale.

Proportioning pump and tank assemblies, available from the ship's parts supply segment of the naval supply system, consist of a 30-gallon mixing tank with a capacity of 24 gallons from top to bottom of the gage glass and a simplex or duplex proportioning pump with a maximum capacity of 2.5 gallons per hour per pump. Some assemblies may differ in the capacity of tank and/or pump. Installation instructions have been issued in SHIPALTS for all classes of ships that use low-pressure, submerged tube or vertical basket type distilling plants. The PD-8 system is installed in some ships when the ship is built.

Dissolve the required amount of PD-8, by stirring, in a bucket of warm water at a temperature not to exceed 100°F. Dump this concentrated solution into the 30-gallon mixing tank, add enough cold water to dilute the solution to a total of 24 gallons, then stir the mixture thoroughly to ensure a uniform solution. This mixing and dilution can be done while the pump continues to deliver PD-8 to the operating evaporator.

The simplex pump consists of one pump and one motor. The duplex pump consists of two pumps, driven by one motor, served by the same mixing tank. Duplex pumps may serve two distilling plants ONLY when the two plants have the same capacity and when these two distilling plants are located in the same compartment. In all other cases simplex pumps must be installed.

With either the simplex or duplex pump, the length of the stroke determines the pump capacity. The stroke is adjusted but is never set at less than 20% because accuracy of the injection rate and lubrication of the pump plunger will be affected. If possible, the pump stroke (or strokes on a duplex pump) should be set to empty the mixing tank, from the top to the bottom of the gage glass, in exactly 24 hours. If this rate of injection should require a pump stroke of less than 20%, then the stroke should be set to empty the tank in less than 24 hours, preferably in 12 or 8 hours to enable easy establishment of a routine for refilling. However, if the time is 12 hours, the solution will contain only half the amount of PD-8 required for a 24-hour period, and the tank must be filled twice a day. If the period of time for emptying the mixing tank is 8 hours, the solution will contain only 1/3 the required daily amount, and the tank must be filled three times each day.

If the pump stroke must be changed, the setting can be made from the indicator scale mounted on the crank arm and verified by checking the amount of time required to empty the mixing tank. The indicator scale is calibrated from 0 to 10. If the pump has a maximum capacity of 7 gph, setting the indicator pointer on 5 will result in a delivery of 3 1/2 gph. To change the stroke, stop the pump and loosen the crankpin locknut. Watch the pointer on the indicator scale, and turn the adjusting screw the required amount. Tighten the crankpin locknut and restart the pump. Check the time required to empty the tank and reset the pump stroke if necessary.

A vacuum drag injection line, used when the proportioner pump fails, runs from the mixing tank to a point downstream (vacuum side) of the feed control valve. A needle valve in the line allows the operator to make relatively fine adjustments in the amount of solution allowed to flow into the evaporator.

For submerged tube and basket-type distilling plants, PD-8 should be injected into the evaporator feed system at a rate not to exceed 1 pound per 10,000 gallons per day distilling plant output. This rate of injection is required during the entire time the plant is in operation. A 4,000-gpd plant requires 4/10 of a pound for a 24-hour period. Two 12,000-gpd plants require the same quantity as a 24,000-gpd plant, or 2.4 pounds per day.

The injection rate of 1 pound per 10,000 gallons per day is a maximum figure; the most effective figure will probably be closer to 3/4 pound. To find the best figure, reduce the amount of PD-8 for each batch. Each mixture should be tried for a week and if no scale is found on the evaporator tubes the amount of PD-8 can be reduced further. If scale forms during this trial, it will gradually crack off when the proper injection rate is established. The brine overboard density should always remain at 1.5 thirty-seconds as the density will influence the effectiveness of the PD-8.

PD-8 feed treatment has proven beneficial for units with more than two stages. In a 50,000-gpd flash type distilling plant, 6.0 pounds of PD-8 should be injected per 24-hour period.

The effectiveness of the PD-8 treatment can be checked by observing the shell temperature in the feedwater heater. Changes in the shell temperature, with the same rate of feedwater flow, indicate changes in the resistance in the heat path between the steam and the feedwater. Increases in the shell temperature indicate a buildup of either scale or PD-8 sludge; the cause can be determined by inspecting the feedwater heater.

In accordance with Planned Maintenance System, the mixing tank should be drained to the bilges and flushed out with freshwater weekly or more often if necessary, to prevent sludge from accumulating in the tank.

Scale Removal

As previously stated in this chapter, the evaporator tubes of a submerged tube type unit MUST be cleaned when the first-effect tube-nest vacuum approaches zero. The vertical-basket type unit should be cleaned when steam pressure of 4 psig or more is required in the first-effect steam chest to produce rated capacity. The flash-type unit will require cleaning when steam pressure of 4 psig is required in the evaporator feedwater heater. Assuming these reductions in capacity are due to scale and not the results of improper operation, an approved cleaning method should be used to remove the scale. The following are some of the approved scale removal methods.

CHILL SHOCKING.–The first-effect tube nest, in which the temperature of the tube nest is near that of the steam supply, tends to scale up more quickly than other parts of the plant. To combat this scale, some method of CHILL SHOCKING (COLD SHOCKING) the tubes is generally provided. This is done by draining the brine from all shells, then reflooding them by means of a hose line connected to a flushing pipe or flooding connection on the shell. This reflooding chills the tube-nest bundles. Steam is then quickly admitted into the tubes, causing differential expansion and contraction which breaks the scale loose from the tubes.

If a feed treatment is not used, the distilling plant should be chill shocked daily. If the Navy standard feed treatment is used, daily chill shocking may be desirable; however, longer intervals are satisfactory.

Chill shocking a submerged-tube evaporator is done as follows:

1. Secure the steam supply to the first-effect tube nest, the tube-nest drain pump and its discharge valve, the distillate pump, and the freshwater pump.

2. Open the emergency circulating water overboard valve at the outlet from the air ejector condenser, and secure the first-effect feed valve.

3. Open wide all interstage feed valves. In plants that have shell drain or pump-out lines connected to the brine pump suction unlock and open wide the valves in these lines.

4. Pump out the brine from all evaporator shells.

5. Connect a hose line to the flushing pipe or flooding connection.

6. Open the hose (water supply) valve to spray or flood the evaporator shells until the tubes in all evaporator shells are fully submerged.

7. Secure the hose valve and again pump out all evaporator shells.

8. Flood all shells again until the tubes in all shells are submerged. This second flooding is to lower the tube bundle temperature as much as possible. When the tubes are fully submerged, secure the hose valve and open quickly the steam supply valve to the first-effect tube nest. The flow of steam will be restricted somewhat by the orifice, if installed, and should be increased by loading the weight-loaded regulating valve to produce not more than 10 psig pressure above the orifice. After the plant has warmed up, cut the pressure back to normal.

9. Start the pumps and regulate the water levels as necessary to put the plant in steady operation.

10. If the plant is one of the earlier installations that has chill shocking and spraying water supply from the fire and flushing main, disconnect the hose line from the flooding or flushing connection to protect the evaporator shells from possible excessive pressure. Such installations should be changed to use the distilling condenser circulating water pump discharge at the earliest opportunity.

Handhole plates are provided on the bottom of the evaporator shells for the removal of scale which has flushed off the tubes.

MECHANICAL CLEANING.–This type of cleaning should be used only as a last resort–chemical clean first. The capacity of a distilling plant is not appreciably reduced by scale deposits on the evaporator tubes until the deposits have caused the first-effect vacuum to be reduced to 1 or 2 inches of mercury. When scale deposits cause the vacuum to approach zero, the tubes MUST be cleaned to keep the plant operating at its maximum efficiency. When the plant is properly operated and the feedwater is treated, the interval between cleanings should be 6 months or longer. The evaporator tube nest must be withdrawn from the shell for cleaning. Lifting gear suitable to the type of installation is usually provided for removing the tube nest.

Submerged Tube Type.–Some evaporators or distilling plants have an overhead trolley from which the tube nest may be suspended for cleaning. Another type has tracks and roller brackets which bolt to the front head of the tube nest. Chain falls can be used to handle the tube nest in small installations.

When the tube nest is withdrawn beyond the support plate, the tube-nest stop should be bolted in place to prevent accidental dropping of the rear head. The tubes are cleaned with a light scaling tool operated by a light air hammer. It should be held against the tube with moderate pressure, and moved over the entire length of the tube. Every tube in the nest must be cleaned, as missing one will impair the output of the plant and also make cleaning more difficult in the future.

NEVER use a torch for descaling a tube nest made up of straight tubes. The expansion and contraction caused by the heat may cause the tubes to loosen at their joints.

After cleaning the tubes, apply a hydrostatic test of 50 psi to the bundle before replacing it within the shell.

When the evaporator tubes are pulled for cleaning, the distillate condenser, air ejector condenser, and the vapor feed heaters should be inspected and cleaned, if necessary. Under some operating conditions, scale deposits may accumulate in these tubes, particularly in the air ejector condenser and the first-effect feed heater.

The distillate condenser on Soloshell plants must be removed for inspection and cleaning. On other types of plants the distillate condenser can be inspected and cleaned by removing the heads at both ends. The air ejector condensers on all plants can be cleaned by removing both heads. The vapor feed heater tubes on practically all designs must be removed for cleaning.

These tube nests are cleaned by means of an extended shank drill, driven by a reversible motor at 250 or 300 rpm, or by standard tube-cleaning equipment adapted for use with 5/8-inch outside diameter condenser tubes.

Flash-Type.–In the flash-type distilling plant, scale formation is reduced to a minimum because the feed is heated under pressure, which prevents boiling, and vapor is formed by free flashing under vacuum. The heat exchanger tubes require periodic cleaning. The tube sheet outer surfaces and tube interiors of the distilling condensers, air ejector condensers, evaporator feedwater heater, and distillate cooler are accessible when the front and rear water boxes are removed. An electric or air-driven cleaning tool may then be pushed through the tubes to remove scale deposits.

CHEMICAL CLEANING.–Chemical cleaning has proven to be faster, more economical, more effective, and less detrimental to evaporator parts than mechanical cleaning. In chemical cleaning, a heated, diluted acid solution is circulated through the saltwater circuits of the system. The two acids most commonly used are hydrochloric and sulfamic. In using these acids which may be harmful to personnel, OBSERVE THE SAFETY PRECAUTIONS AND FOLLOW THE PROCEDURES LISTED in chapter 531 (9580-II) of *NAVSHIPS' Technical Manual.*

Hydrochloric acid comes in liquid form and presents hazards in handling and storing. The use of hydrochloric acid is authorized ONLY when properly supervised by qualified naval shipyard personnel, NEVER by ship's force alone.

Sulfamic acid comes in powdered form and is safe for storage aboard ship, when stored in the original containers. The use of sulfamic acid is authorized under the supervision of qualified tender or naval shipyard personnel. At the discretion of type commanders, individual ships may be authorized to carry sulfamic acid, and cleaning may be performed by qualified personnel in the ship's crew. Cleaning can be accomplished by passing 50-gallon slugs of solution through the feed and brine systems while the plant is in operation. A solution containing 100 gallons of seawater or freshwater and 50 pounds of sulfamic acid powder can be injected into the distilling plant in two ways: by taking feed pump suction through a hose-valve assembly directly from a container of acid solution or by using the plant vacuum to draw in the solution. Regardless of the method of injection used, the solution should be injected as rapidly as possible. The distilling plant should remain in operation so the solution will be heated as it passes through. The plant may be unbalanced by interruptions in flow but will settle down quickly when the feedwater flow is again constant.

Careless handling of the acid solution can result in injury to personnel and equipment. The chemicals are harmful to the eyes and skin. If possible the chemicals should be handled by mechanical means rather than manually; protective clothing should be worn at all times during cleaning operations.

Chapter 531 (9580-II) of *NAVSHIPS' Technical Manual,* has a complete list of safety precautions and procedures which must be carefully followed when chemically cleaning distilling plant tubes.

TESTING FOR SALTWATER LEAKS

If a leak is detected in a heat exchanger, the defective tube(s) should be located by an air test or a hydrostatic test, in accordance with the recommended procedure in the manufacturer's instructions. Blueprints should also be used to study the construction details of the individual heat exchanger.

As soon as a leaky tube has been located, it should be plugged at both ends. Special composition plugs, which are provided in the allowance of repair parts, should be used.

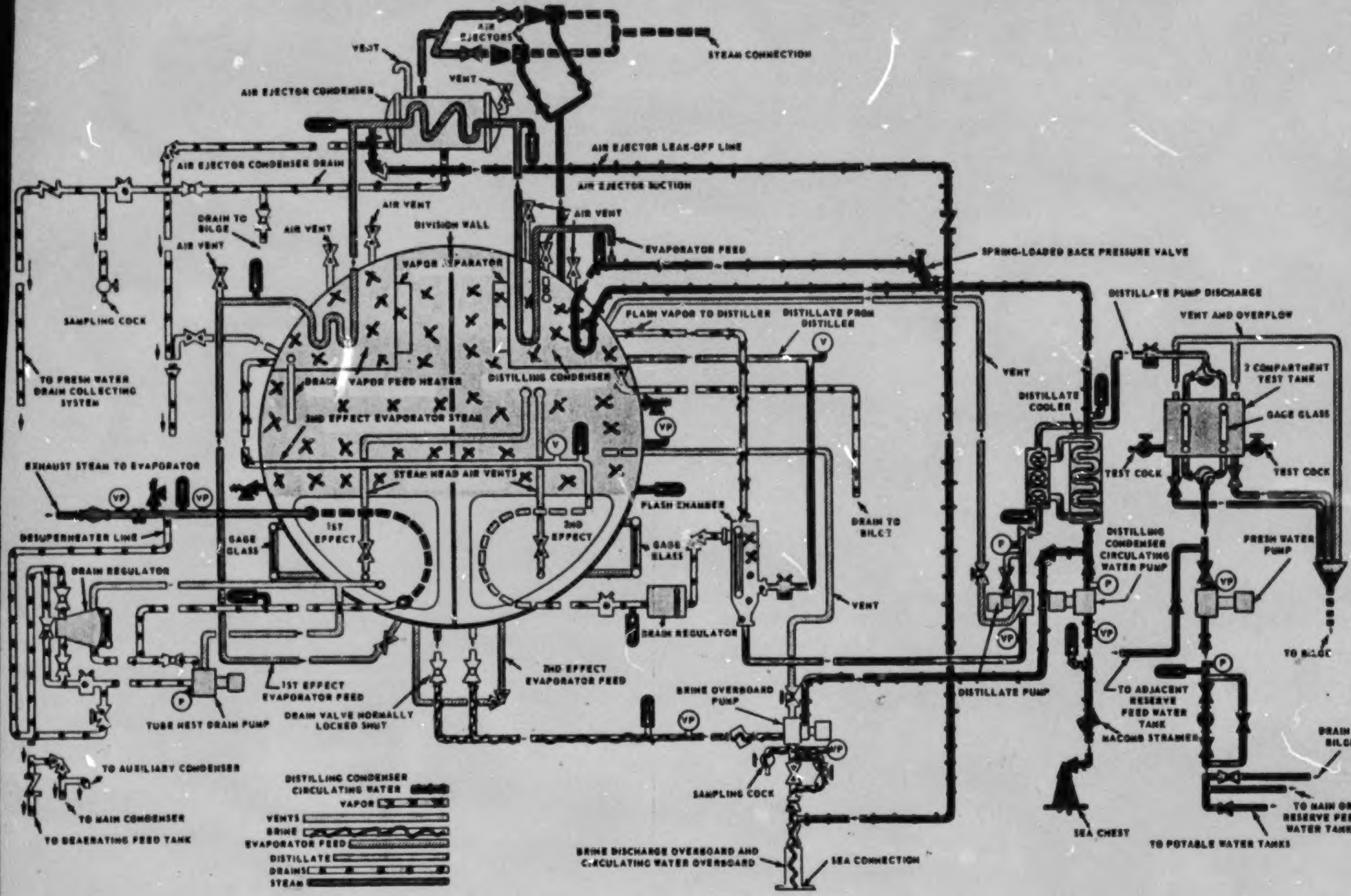
Since plugging the tubes reduces the amount of heating surface, the heat exchanger will fail to give satisfactory performance after a number of tubes have been plugged. It will then become necessary to retube the heat exchanger. Under normal conditions, this work should be accomplished by a naval shipyard or tender. However, repair parts and a number of special tools are included in the Ship's Allowance List so that emergency repairs can be made to the heat exchangers and to other parts of the distilling plant.

To find which tube within a REMOVABLE TUBE BUNDLE is leaking, it is necessary to test the individual bundles hydrostatically. If the leak is in a removable bundle (vapor feed heaters when within an evaporator shell, evaporator tube nests, distillate condensers on Soloshell end-pull plants), the bundle must be withdrawn and a hydrostatic test at full pressure (50 psi) must be applied on the tube side.

If a leak occurs in a NONREMOVABLE TUBE BUNDLE (distillate cooler, air ejector condenser, external vapor feed heaters), the tube nest covers must be removed, and the full test pressure (50 psi) must be applied on the shell side of the unit.

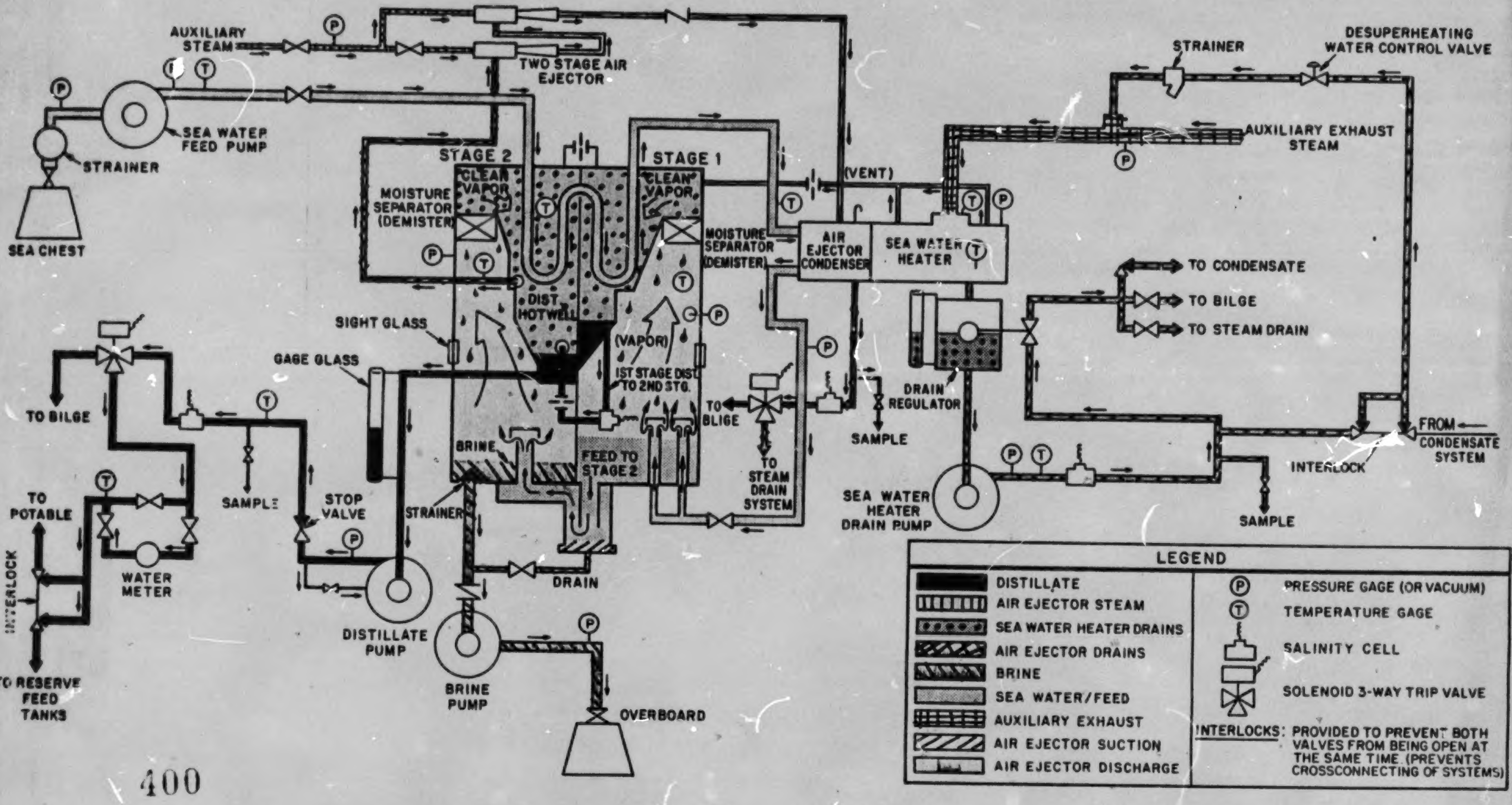
If a nonremovable distillate condenser bundle is within an evaporator shell, the tube nest covers must be removed and a full test pressure of 30 psi should be applied to the evaporator shell.

If the distillate condenser is fitted with a diaphragm-tube (Goubert) expansion joint, a test ring will be required to replace the tube nest cover for testing.


AIR EJECTORS
STEAM CONNECTION
VENT
AIR EJECTOR CONDENSER
VENT
AIR EJECTOR LEAK-OFF LINE
AIR EJECTOR CONDENSER DRAIN
AIR EJECTOR SUCTION
DRAIN TO BILGE
AIR VENT
AIR VENT
AIR VENT
AIR VENT
DIVISION WALL
EVAPORATOR FEED
SPRING-LOADED BACK PRESSURE VALVE
VAPOR SEPARATOR
SAMPLING COCK
FLASH VAPOR TO DISTILLER
DISTILLATE FROM DISTILLER
DISTILLATE PUMP DISCHARGE
VENT AND OVERFLOW
2 COMPARTMENT TEST TANK
GAGE GLASS
TO FRESH WATER DRAIN COLLECTING SYSTEM
DRAIN
VAPOR FEED HEATER
DISTILLING CONDENSER
VENT
DISTILLATE COOLER
2ND EFFECT EVAPORATOR STEAM
TEST COCK
TEST COCK
EXHAUST STEAM TO EVAPORATOR
STEAM HEAD AIR VENTS
VP
VP
VP
V
V
DRAIN TO BILGE
DESUPERHEATER LINE
1ST EFFECT
2ND EFFECT
FLASH CHAMBER
GAGE GLASS
GAGE GLASS
DISTILLING CONDENSER CIRCULATING WATER PUMP
FRESH WATER PUMP
DRAIN REGULATOR
DRAIN REGULATOR
VENT
P
TO BILGE
1ST EFFECT EVAPORATOR FEED
2ND EFFECT EVAPORATOR FEED
DISTILLATE PUMP
TO ADJACENT RESERVE FEED WATER TANK
TUBE NEST DRAIN PUMP
DRAIN VALVE NORMALLY LOCKED SHUT
BRINE OVERBOARD PUMP
MACOMB STRAINER
DRAIN TO BILGE
TO AUXILIARY CONDENSER
SAMPLING COCK
TO MAIN CONDENSER
TO DEAERATING FEED TANK
SEA CHEST
TO MAIN OR RESERVE FEED WATER TANKS
TO POTABLE WATER TANKS
BRINE DISCHARGE OVERBOARD AND CIRCULATING WATER OVERBOARD
SEA CONNECTION
DISTILLING CONDENSER CIRCULATING WATER
VAPOR
VENTS
BRINE
EVAPORATOR FEED
DISTILLATE
DRAINS
STEAM

47.114

Figure 17-3.—Schematic diagram of Soloshell double-effect distilling unit.


AUXILIARY STEAM
TWO STAGE AIR EJECTOR
SEA WATER FEED PUMP
STRAINER
SEA CHEST
STAGE 2
STAGE 1
CLEAN VAPOR
CLEAN VAPOR
MOISTURE SEPARATOR (DEMISTER)
MOISTURE SEPARATOR (DEMISTER)
DIST HOTWELL
(VAPOR)
IST STAGE DIST TO 2ND STG.
SIGHT GLASS
GAGE GLASS
BRINE
FEED TO STAGE 2
STRAINER
DRAIN
TO BLIGE
TO STEAM DRAIN SYSTEM
(VENT)
AIR EJECTOR CONDENSER
SEA WATER HEATER
SAMPLE
DRAIN REGULATOR
SEA WATER HEATER DRAIN PUMP
STRAINER
DESUPERHEATING WATER CONTROL VALVE
AUXILIARY EXHAUST STEAM
TO CONDENSATE
TO BILGE
TO STEAM DRAIN
FROM CONDENSATE SYSTEM
INTERLOCK
SAMPLE
TO BILGE
SAMPLE
STOP VALVE
TO POTABLE
INTERLOCK
WATER METER
TO RESERVE FEED TANKS
DISTILLATE PUMP
BRINE PUMP
OVERBOARD
LEGEND
DISTILLATE
AIR EJECTOR STEAM
SEA WATER HEATER DRAINS
AIR EJECTOR DRAINS
BRINE
SEA WATER/FEED
AUXILIARY EXHAUST
AIR EJECTOR SUCTION
AIR EJECTOR DISCHARGE
P PRESSURE GAGE (OR VACUUM)
T TEMPERATURE GAGE
SALINITY CELL
SOLENOID 3-WAY TRIP VALVE
INTERLOCKS: PROVIDED TO PREVENT BOTH VALVES FROM BEING OPEN AT THE SAME TIME. (PREVENTS CROSSCONNECTING OF SYSTEMS)

47.211

Figure 17-9.—2-stage flash-type distilling plant 12,000 gpd capacity.

CHAPTER 18

REFRIGERATION

As an Engineman, you must have a knowledge of refrigeration and air conditioning systems. From practical experience, you will learn how to start, operate, stand watch on, and secure these systems. To do your job properly, you must have a thorough understanding of the operating principles of refrigeration systems. You can attain this understanding through study.

The refrigeration systems most commonly used by the Navy use R-12 as a refrigerant. Chemically, R-12 is dichlorodifluoromethane (CCl_2F_2). R-12 has such a low boiling point that it cannot exist as a liquid unless it is confined in a container designed for pressure. R-12 also has several advantages; it is practically nontoxic, nonflammable, nonexplosive, and noncorrosive and does not poison or contaminate foods. The information in this chapter is primarily concerned with R-12 systems. However, the cycle of operation and the main components of R-12 systems are basically the same for other refrigeration and air conditioning plants.

FUNDAMENTALS OF REFRIGERATION

Refrigeration is a general term that describes the process of removing heat from spaces, objects, or materials and maintaining them at temperatures below the temperature of the surrounding atmosphere. To produce a refrigeration effect, the material to be cooled needs only to be exposed to a colder object or environment; the heat will flow in its NATURAL direction—that is, from the warmer material to the colder material. Refrigeration, then, usually means an artificial way of lowering the temperature. Mechanical refrigeration is a mechanical system or apparatus so designed and constructed that, through its function, heat is transferred from one substance to another.

You will more readily understand refrigeration if you know the relationships among temperature, pressure, and volume, and how pressure affects liquids and gases.

HEAT

The purpose of refrigeration is to maintain spaces at low temperatures. Remember, however, that you cannot cool anything by adding coolness to it; you have to REMOVE HEAT from it. Refrigeration, therefore, is a process of cooling by removing heat.

Heat and Temperature

It is important to distinguish between heat and temperature. HEAT is a form of energy. TEMPERATURE is the intensity of heat. The quantity or amount of heat energy in a substance is measured in BRITISH THERMAL UNITS (Btu). The Btu is the amount of heat required to raise the temperature of 1 pound of pure water 1°F. Temperature, as you know, is measured in degrees which indicate the intensity of the heat in a given substance; it does not indicate the number of Btu's in the substance. For example, let's consider a spoonful of very hot water and a bucketful of warm water. Which has the higher temperature? Which has more heat? The heat in the spoonful of hot water is more intense; therefore, its temperature is higher. The bucketful of warm water has more

Btu (more heat energy), but its heat is less intense.

Sensible Heat and Latent Heat

In the study of refrigeration, you must distinguish between sensible heat and latent heat. Sensible heat is the heat absorbed or given off by a substance that is NOT in the process of changing its physical state. When a substance is not in the process of changing its state, the addition or removal of heat always causes a change in the temperature of the substance. Sensible heat can be sensed, or measured with a thermometer.

Latent heat is the heat absorbed or given off by a substance while it is changing its physical state. When a substance is in process of changing its physical state, the heat absorbed or given off does NOT cause a temperature change in the substance—the heat is latent or hidden. In other words, sensible heat is the heat that affects the temperature of things; latent heat is the heat that affects the physical state of things. You will find more information on sensible heat and latent heat in chapter 3 of *Fireman*, NAVEDTRA 10520.

Specific Heat

Substances vary with respect to their ability to absorb or lose heat. The ability of a substance to absorb heat or to lose it is known as the specific heat of the substance. The specific heat of water is 1.0 (1 Btu/lb/°F), and the specific heat of each other substance is measured by comparison with this standard. Thus, if it takes only 1/2 Btu to raise the temperature of 1 pound of a substance 1°F, the specific heat of that substance is 0.5, or one-half the specific heat of water. If you look up the specific heat of ice in a table, you will find it to be approximately 0.5.

Heat Flow

Heat flows only from objects of higher temperature to objects of lower temperature. When two objects at different temperatures are placed near each other, heat will flow from the warmer object to the cooler one until both objects are at the same temperature. Heat flow takes place at a greater rate when there is a large temperature difference than when there is only a slight temperature difference. As the temperature difference approaches zero, the rate of heat flow also approaches zero. Heat flow may take place by radiation, by conduction, by convection, or by some combination of these methods.

Refrigeration Ton

The unit of measure for the amount of heat removed is known as the refrigeration ton. The capacity of a refrigeration unit is usually stated in refrigeration tons. The refrigeration ton is based on the cooling effect of 1 ton (2,000 pounds) of ice at 32°F melting in 24 hours. The latent heat of fusion of ice (or water) is 144 Btu. Therefore, the number of Btu's required to melt 1 ton of ice is 144 X 2,000 = 288,000. The standard refrigeration ton is defined as the transfer of 288,000 Btu in 24 hours. On an hourly basis, the refrigeration ton is 12,000 Btu per hour (288,000 is divided by 24).

The refrigeration ton is the standard unit of measure used to designate the heat-removal capacity of a refrigeration unit. It is not a measure of the ice-making capacity of a machine, since the amount of ice that can be made depends on the initial temperature of the water and other factors.

PRESSURE, TEMPERATURE, AND VOLUME

As stated earlier, it is important that you understand some of the ways pressure affects liquids and gases, and some of the relationships between pressure, temperature, and volume in gases.

The boiling point of any liquid varies according to the pressure on the liquid—the higher the pressure, the higher the boiling point. It is well to remember that condensing a gas to a liquid is just the reverse process of boiling a liquid until it vaporizes and that the same pressure and temperature relationship is required to produce either change of state.

Water boils at 80°F under a vacuum of 29 inches of mercury and at 489°F at a pressure of 600 psig. Refrigerants used in vapor compressor cycle equipment usually have much lower boiling points than water, under any given pressure, but these boiling points also vary according to pressure. R-12, for example, boils at -21°F at atmospheric pressure; at 0°F at 9.17 psig; at 50°F at 46.69 psig; and at 100°F at 116.9 psig. From these figures, you can see that R-12 cannot exist as a liquid at ordinary temperatures unless it is confined in a container to maintain its own pressure.

If the temperature of a liquid is raised to the boiling point corresponding to its pressure and if application of heat is continued, the liquid begins to boil and vaporize. The vapor that is formed remains at the same temperature as the boiling liquid, as long as it is in contact with the liquid. A vapor CANNOT be superheated as long as it is in contact with the liquid from which it is being generated.

The pressure-temperature-volume relationships of gases are expressed by Boyle's law, Charles' law, and the general gas law or equation.

BOYLE'S LAW states that the volume of any dry gas varies inversely with its absolute pressure, provided the temperature remains constant. This law may also be expressed as

$$V_1P_1 = V_2P_2$$

where V_1 is the original volume of the gas, P_1 its original absolute pressure, V_2 its new volume, and P_2 its new absolute pressure.

CHARLES' LAW states that the volume of a gas is directly proportional to its absolute temperature, provided the pressure is kept constant. The equation for this law is

$$V_1T_2 = V_2T_1$$

THE GENERAL GAS EQUATION combines Boyle's law and Charles' law, and expresses the interrelationship of the volume, the absolute pressure, and the absolute temperature of gases. The general gas law is expressed by

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

These equations indicate the nature of the interrelationship of the pressure, the volume, and the temperature of any gas. You probably will not find it necessary to use the equations themselves, but you should have a thorough understanding of the principles which they express. Let's summarize them:

1. When temperature is held constant, increasing the pressure on a gas causes a proportional decrease in volume; decreasing the pressure causes a proportional increase in volume.

2. When pressure is held constant, increasing the temperature of a gas causes a proportional increase in volume; decreasing the temperature causes a proportional decrease in volume.

3. When the volume is held constant, increasing the temperature of a gas causes a proportional increase in pressure; decreasing the temperature causes a proportional decrease in pressure.

In this discussion of the effects of pressure on a gas, we have pointed out that the volume and the temperature of gas are different AFTER the pressure has been changed. It is important to note, however, that a temperature change normally occurs in a gas WHILE the pressure is being changed. Compressing a gas raises its temperature; allowing a gas to expand lowers its temperature. As you will see, this fact is of importance in the refrigeration cycle.

MECHANICAL REFRIGERATION SYSTEMS

Various types of refrigerating systems are used for naval shipboard refrigeration and air conditioning. The one most generally employed for refrigeration purposes is the vapor compression cycle with reciprocating compressors. Vapor compression cycle refrigerating systems with centrifugal compressors (described in chapter 19) are oftentimes used for air conditioning. Centrifugal units are generally used to cool a secondary refrigerant such as brine or cargo refrigeration and freshwater for air conditioning application.

The vapor compression cycle with reciprocating compressors using R-12 is used for most naval refrigerating plants. Figure 18-1 gives a general idea of this type refrigeration cycle. As you study this system, try to understand what happens to the refrigerant as it passes through each part of the cycle. In particular, be sure that you understand why the refrigerant changes from liquid to vapor and from vapor to liquid, and what happens in terms of heat because of these changes of state. It will be helpful to trace the refrigerant through its entire cycle, beginning with the thermostatic expansion valve.

Liquid refrigerant enters the expansion valve from the high-pressure side of the system and passes through an orifice, which reduces the pressure of the refrigerant. Due to the reduction in pressure, the liquid refrigerant begins to boil and to flash into vapor.

From the thermostatic expansion valve, the refrigerant passes into the cooling coil (or evaporator). The boiling point of the refrigerant under the low pressure in the evaporator is about 20°F lower than the temperature of the space in which the cooling coil is installed. As the liquid boils and vaporizes, it picks up its latent heat of vaporization from the surroundings, thereby removing heat from the space. The refrigerant continues to absorb latent heat of vaporization until all the liquid has been vaporized. By the time the refrigerant is ready to leave the cooling coil, it has not only absorbed this latent heat of vaporization, but has also picked up some additional heat—that is, the vapor has become superheated. As a rule, the amount of superheat is 4° to 12°F.

The refrigerant leaves the evaporator as low-pressure superheated vapor, having absorbed heat and thus cooled the space to the desired temperature. The remainder of the cycle is concerned with disposing of this heat and converting the refrigerant back into a liquid state so that it can again vaporize in the evaporator and thus again absorb the heat.

The low-pressure superheated vapor is drawn out of the evaporator by the compressor, which also keeps the refrigerant circulating through the system. In the compressor cylinders, the refrigerant is compressed from a low-pressure, low-temperature vapor to a high-pressure vapor, and its temperature rises accordingly.

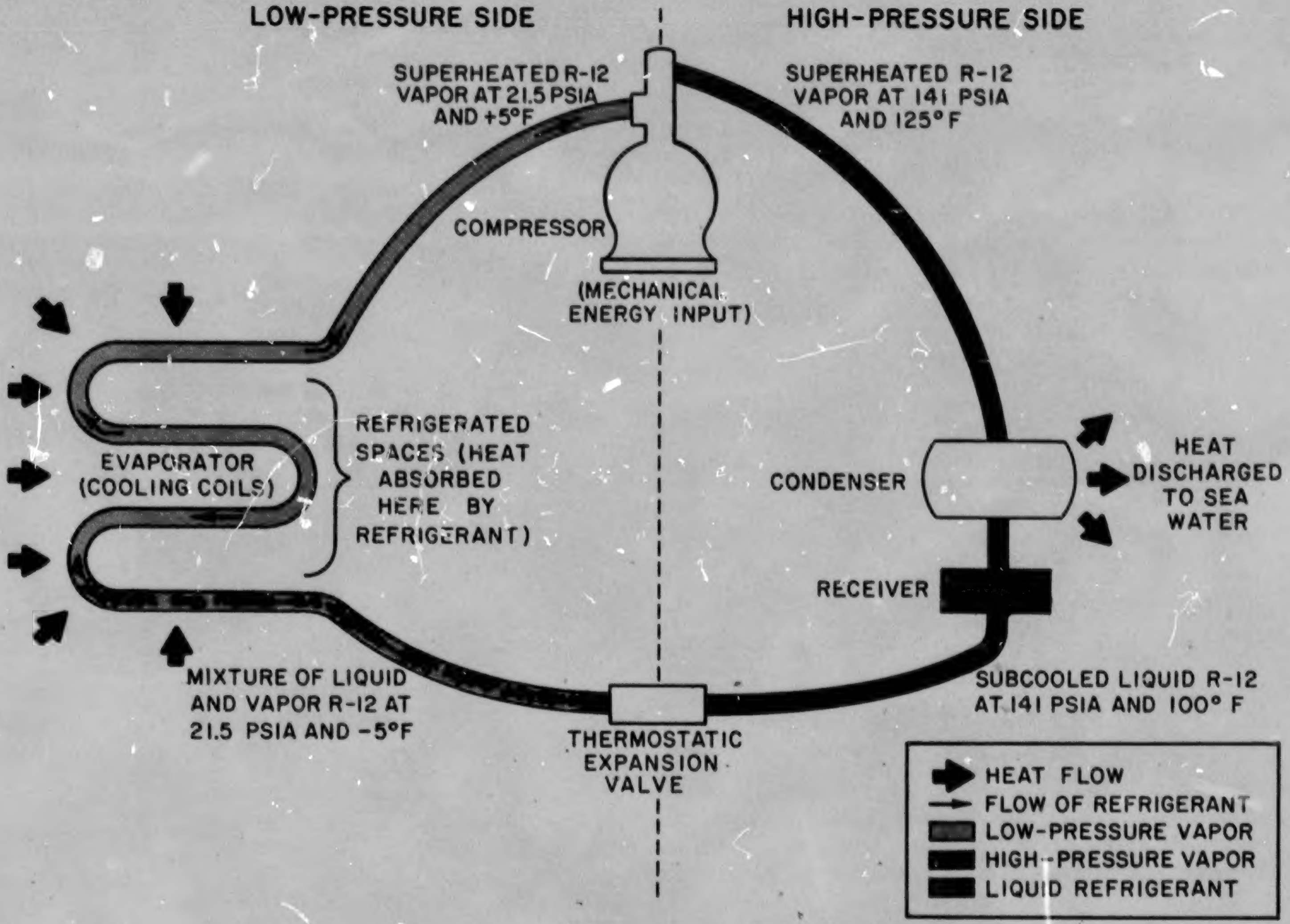
The high-pressure R-12 vapor is discharged from the compressor into the condenser. Here the refrigerant condenses, giving up its superheat (sensible heat) and its latent heat of condensation to the ambient air in an air-cooled condenser or the cooling water in a water-cooled condenser. The refrigerant, still at high pressure, is now a liquid again.

From the condenser, the refrigerant flows into a receiver which serves as a storage place for the liquid refrigerant in the system. From the receiver, the refrigerant goes to the thermostatic expansion valve, and the cycle begins again.

This type of refrigeration system has two pressure sides. The LOW-PRESSURE SIDE extends from the orifice of the thermostatic expansion valve up to and including the intake side of the compressor cylinders. The HIGH-PRESSURE SIDE extends from the discharge valve of the compressor to the thermostatic expansion valve. Figure 18-2 shows most of the components on the high-pressure side of an R-12 system, as actually installed aboard ship.

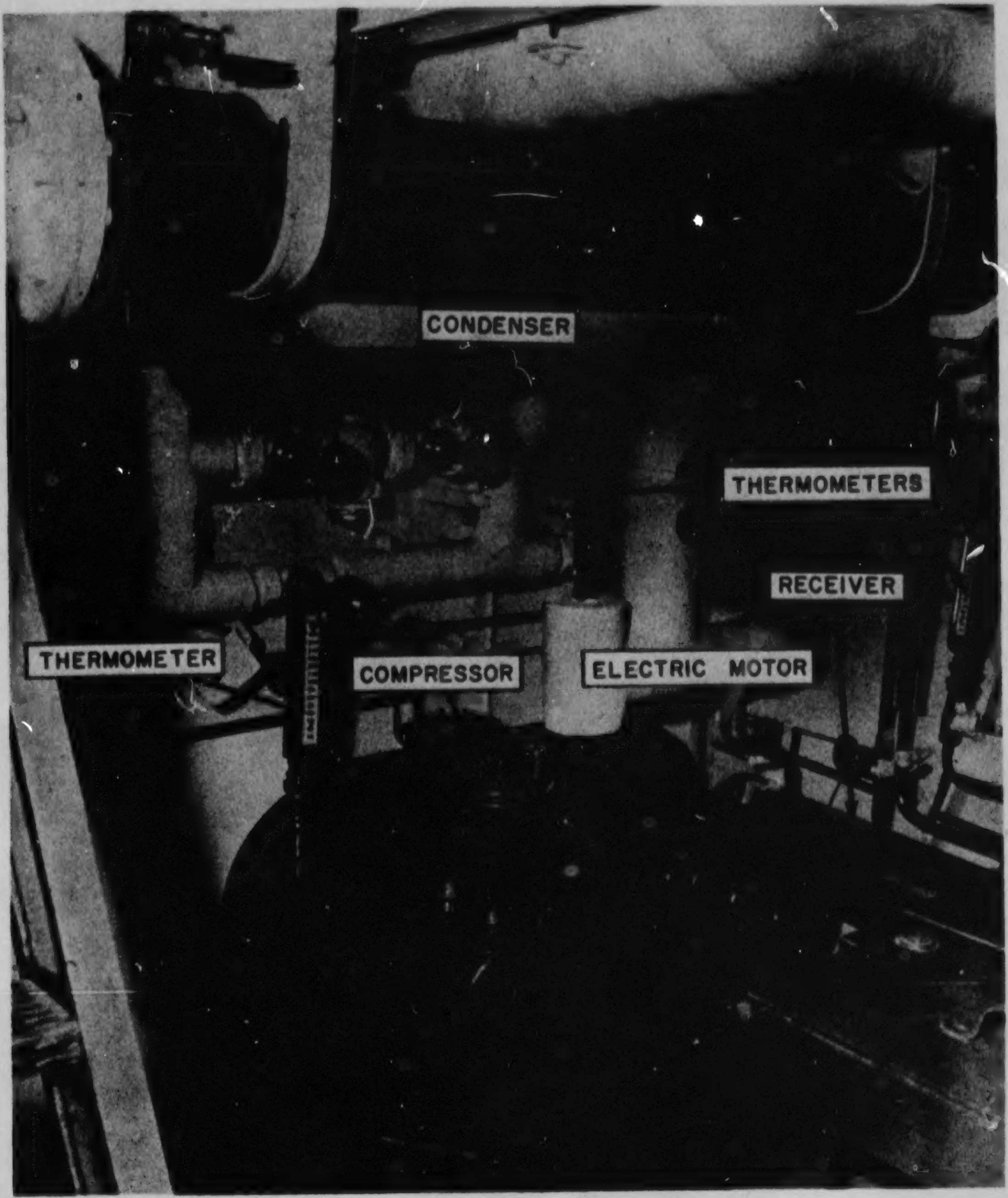
MAIN PARTS OF THE R-12 SYSTEM

The main parts of an R-12 refrigeration system are shown diagrammatically in figure 18-3. The primary components of the system are the thermostatic expansion valve, the evaporator, the compressor, the condenser, and the receiver. Additional equipment required to


LOW-PRESSURE SIDE
HIGH-PRESSURE SIDE
SUPERHEATED R-12 VAPOR AT 21.5 PSIA AND +5°F
SUPERHEATED R-12 VAPOR AT 141 PSIA AND 125°F
COMPRESSOR
(MECHANICAL ENERGY INPUT)
REFRIGERATED SPACES (HEAT ABSORBED HERE BY REFRIGERANT)
EVAPORATOR (COOLING COILS)
CONDENSER
HEAT DISCHARGED TO SEA WATER
RECEIVER
MIXTURE OF LIQUID AND VAPOR R-12 AT 21.5 PSIA AND -5°F
THERMOSTATIC EXPANSION VALVE
SUBCOOLED LIQUID R-12 AT 141 PSIA AND 100° F
HEAT FLOW
FLOW OF REFRIGERANT
LOW-PRESSURE VAPOR
HIGH-PRESSURE VAPOR
LIQUID REFRIGERANT

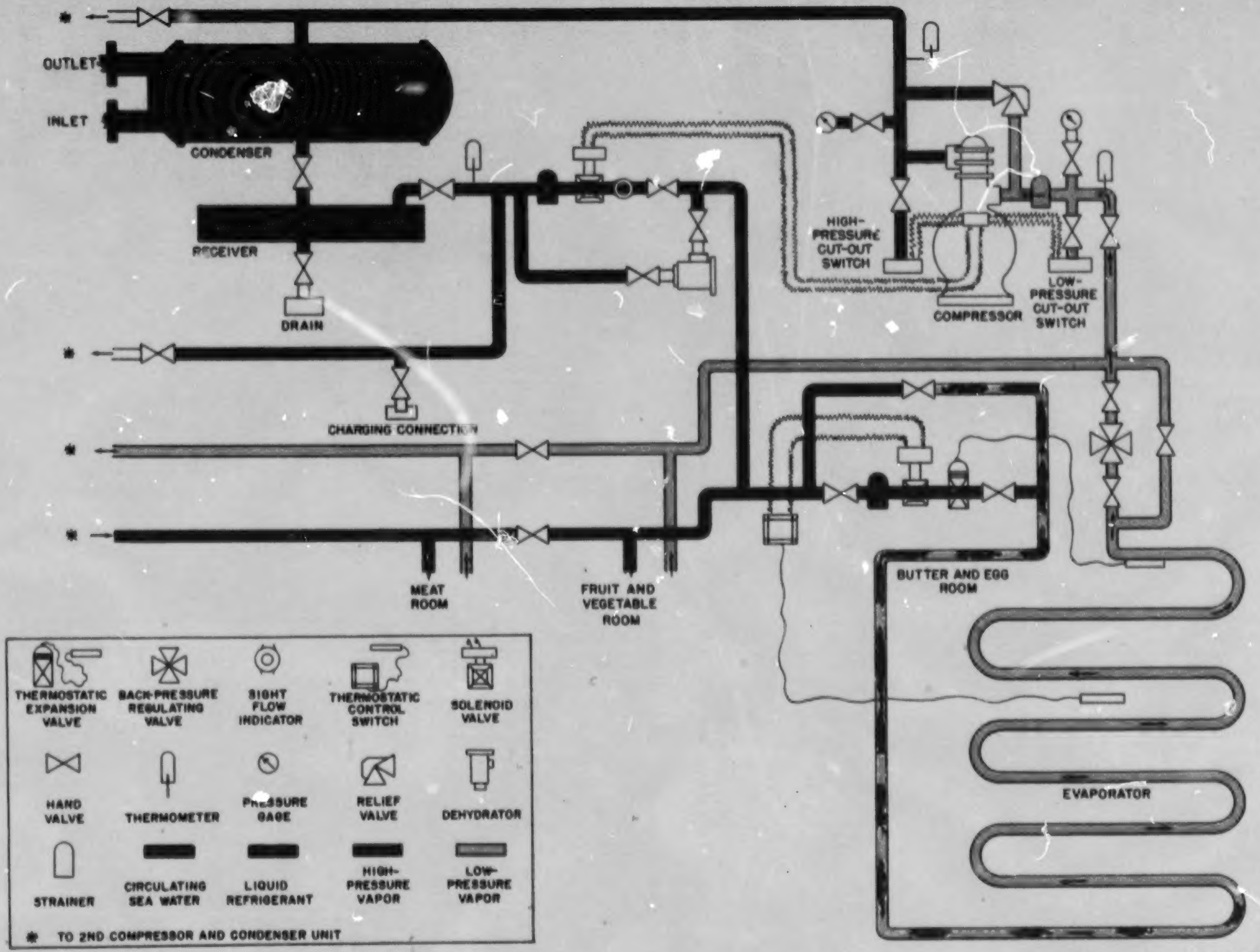
C47.90

Figure 18-1.—Schematic representation of R-12 refrigeration cycle.


CONDENSER
THERMOMETERS
RECEIVER
THERMOMETER
COMPRESSOR
ELECTRIC MOTOR

47.92

Figure 18-2.—High-pressure side of R-12 installation aboard ship.


OUTLET
INLET
CONDENSER
RECEIVER
DRAIN
CHARGING CONNECTION
HIGH-PRESSURE CUT-OUT SWITCH
COMPRESSOR
LOW-PRESSURE CUT-OUT SWITCH
MEAT ROOM
FRUIT AND VEGETABLE ROOM
BUTTER AND EGG ROOM
EVAPORATOR
THERMOSTATIC EXPANSION VALVE
BACK-PRESSURE REGULATING VALVE
SIGHT FLOW INDICATOR
THERMOSTATIC CONTROL SWITCH
SOLENOID VALVE
HAND VALVE
THERMOMETER
PRESSURE GAGE
RELIEF VALVE
DEHYDRATOR
STRAINER
CIRCULATING SEA WATER
LIQUID REFRIGERANT
HIGH-PRESSURE VAPOR
LOW-PRESSURE VAPOR
* TO 2ND COMPRESSOR AND CONDENSER UNIT

C47.91

Figure 18-3.—Diagram of an R-12 refrigeration system.

complete the plant includes piping, pressure gages, thermometers, various types of control switches and control valves, strainers, relief valves, sight-flow indicators, dehydrators, and charging connections.

In the following discussion, we will deal with the R-12 system as though it had only one evaporator, one compressor, and one condenser. As you can see from figure 18-3 however, a refrigeration system may (and usually does) include more than one evaporator, and it may include additional compressor and condenser units.

Thermostatic Expansion Valve

The thermostatic expansion valve is essentially a reducing valve between the high-pressure side and the low-pressure side of the system. The valve is designed to regulate the rate at which the refrigerant enters the cooling coil in proportion to the rate of evaporation of the liquid refrigerant in the coil; the amount depends, of course, on the amount of heat being removed from the refrigerated space.

A thermal control bulb for the thermostatic expansion valve is clamped to the cooling coil, near the outlet. The bulb contains R-12. Control tubing connects the bulb with the area above the diaphragm in the thermostatic expansion valve. When the temperature at the control bulb rises, the R-12 expands and transmits a pressure to the diaphragm; this causes the diaphragm to be moved downward, thus opening the valve and allowing more refrigerant to enter the cooling coil. When the temperature at the control bulb falls, the pressure above the diaphragm decreases and the valve tends to close. Thus, the temperature near the evaporator outlet controls the operation of the thermostatic expansion valve.

Evaporator

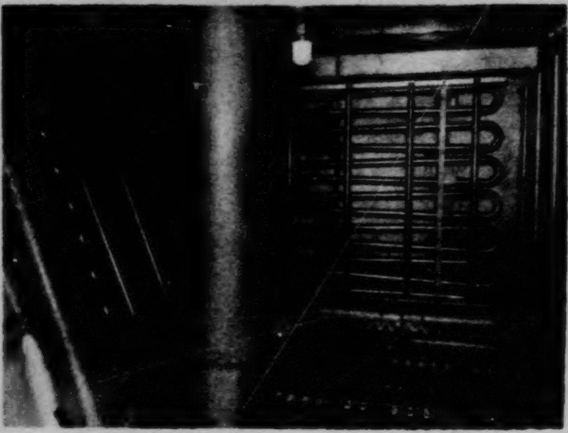
The evaporator consists of a coil of copper, aluminum, or aluminum alloy tubing installed in the space to be refrigerated. Figure 18-4 illustrates some of this tubing. As mentioned before, the liquid R-12 enters the tubing at a very much reduced pressure and, therefore, with a very much lowered boiling point. In passing through the expansion valve, part of the refrigerant boils and vaporizes, due to the reduced pressure, and the remaining liquid refrigerant is cooled to its boiling point. Then, as the refrigerant passes through the evaporator, the heat flowing to the coil from the surrounding air causes the rest of the liquid refrigerant to boil and vaporize. After the refrigerant has absorbed its latent heat of vaporization (that is, after it is entirely vaporized), the refrigerant continues to absorb heat until it becomes superheated by approximately 10°F. The amount of superheat is determined by the amount of liquid refrigerant admitted to the evaporator; and this, in turn, is controlled by the spring adjustment of the thermostatic expansion valve. A temperature range of 4° to 12°F of superheat is considered desirable because it increases the efficiency of the plant and because it evaporates all of the liquid, thus preventing liquid carryover into the compressor.

Compressor

The compressor in a refrigeration system is essentially a pump. It is used to pump heat "uphill" from the cold side to the hot side of the system.

The heat absorbed by the refrigerant in the evaporator must be removed before the refrigerant can again absorb latent heat. The only way the vaporized refrigerant can be made to give up the latent heat of vaporization that it absorbed in the evaporator is by cooling and condensing it. Because of the relatively high temperature of the available cooling medium, the only way to make the vapor condense is by first compressing it.

The vapor drawn into the compressor is at very low pressure and very low temperature. In the compressor, both the pressure and the temperature are raised. Since an increase in pressure causes a proportional rise in



47.93

Figure 18-4.—Evaporator tubing.

temperature and since the condensation point of any vapor is dependent on the pressure, raising the pressure of the vaporized refrigerant provides a condensation temperature high enough to permit the use of seawater as the condensing and cooling medium. The compressor raises the pressure of the vaporized refrigerant sufficiently high to permit condensation to take place in the condenser.

In addition to this primary function, the compressor also keeps the refrigerant circulating and maintains the required pressure difference between the high-pressure side and the low-pressure side of the system.

Many different types of compressors are used in refrigeration systems. The designs of compressors vary depending on the application of the refrigerants used in the system. Figure 18-5 shows a motor-driven, single-acting, two-cylinder, reciprocating compressor such as is commonly used in naval refrigeration plants.

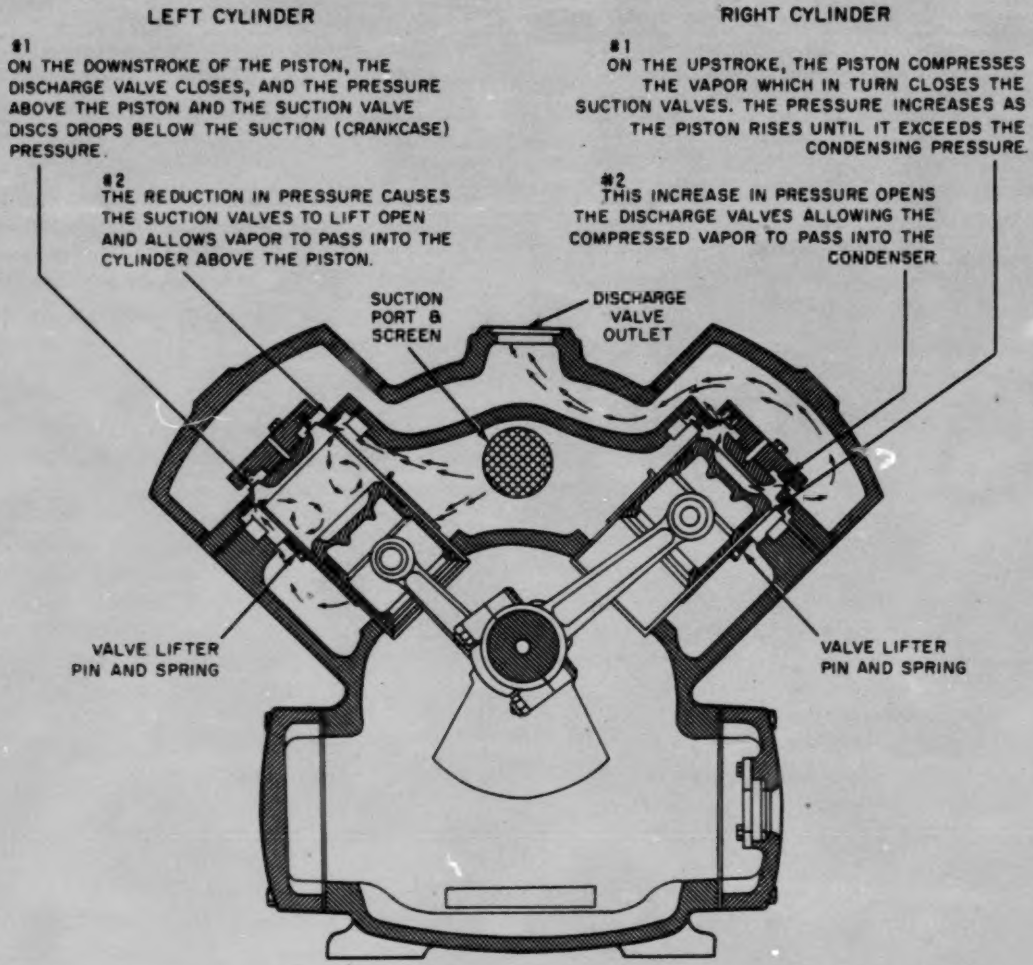
Compressors used in R-12 systems may be lubricated either by pressure lubrication or by splash lubrication. Splash lubrication, which depends on maintaining a fairly high oil level in the compressor crankcase, is usually satisfactory for smaller compressors. High speed or large capacity compressors use pressure lubrication systems.

SHAFT SEALS.—Where the crankshaft extends through the crankcase, a leakproof seal must be maintained to prevent the refrigerant from escaping and also to prevent air from entering the crankcase when the pressure in the crankcase is lower than the surrounding atmospheric pressure. This is accomplished by crankshaft seal assemblies. There are several types of seals such as the rotary seal, the stationary bellows, the rotating bellows, and the diaphragm.

The rotary seal shown in figure 18-6 consists of a stationary cover plate and gasket, a rotating assembly which includes a carbon ring, a neoprene seal, a compression spring, and compression washers. The sealing points are (a) between the crankshaft and the rotating carbon rings and sealed by a neoprene ring, (b) between the rotating carbon ring and the cover plate and sealed by lapped surfaces, and (c) between the cover plate and the crankcase and sealed by a metallic gasket. The seal is adjusted by adding or removing metal washers between the crankshaft shoulder and the shaft seal compression spring.

A stationary bellows seal is illustrated in figure 18-7. It consists of a bellows clamped to the compressor housing at one end to form a seal against a rotating shaft seal collar on the other. The sealing points are (a) between the crankcase and the bellows and sealed by the cover plate gasket, (b) between the crankshaft and the shaft seal collar and sealed by a neoprene gasket, and (c) between the surface of the bellows nose and the surface of the seal collar and sealed by lapped surfaces. The stationary bellows seal is factory set for proper tension and should not be altered.

The rotating bellows seals, figure 18-8, consists of a bellows clamped to the crankshaft at one end to form a seal against a stationary, removable shaft seal shoulder on the other end. The sealing points are located (a) between the crankshaft and bellows and sealed by a shaft seal clamping nut, (b) between the removable shaft seal shoulder and the crankcase and sealed by a



LEFT CYLINDER

#1
ON THE DOWNSTROKE OF THE PISTON, THE DISCHARGE VALVE CLOSES, AND THE PRESSURE ABOVE THE PISTON AND THE SUCTION VALVE DISCS DROPS BELOW THE SUCTION (CRANKCASE) PRESSURE.

#2
THE REDUCTION IN PRESSURE CAUSES THE SUCTION VALVES TO LIFT OPEN AND ALLOWS VAPOR TO PASS INTO THE CYLINDER ABOVE THE PISTON.

RIGHT CYLINDER

#1
ON THE UPSTROKE, THE PISTON COMPRESSES THE VAPOR WHICH IN TURN CLOSES THE SUCTION VALVES. THE PRESSURE INCREASES AS THE PISTON RISES UNTIL IT EXCEEDS THE CONDENSING PRESSURE.

#2
THIS INCREASE IN PRESSURE OPENS THE DISCHARGE VALVES ALLOWING THE COMPRESSED VAPOR TO PASS INTO THE CONDENSER.

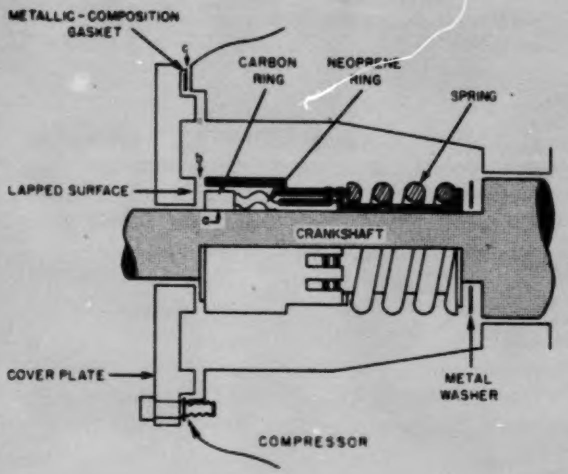
47.215

Figure 18-5.—Reciprocating compressor.

neoprene gasket, and (c) between the bellows nose piece and the shaft seal collar and sealed by lapped surfaces. This type seal is also factory set.

The diaphragm seal, figure 18-9, consists of a diaphragm clamped to the crankcase at its outer circumference and to a fulcrum ring at its center. The fulcrum ring forms a seal collar which is locked to the diaphragm. The sealing points are located (a) between the outer circumference of the diaphragm and the crankcase and sealed by a copper ring gasket, (b) between the fulcrum ring and the diaphragm—sealed at the factory and not to be broken, (c) between the fulcrum ring and the rotating shaft seal collar and sealed by lapped surfaces, and (d) between the shaft seal collar and the crankshaft shoulder and also sealed by lapped surfaces.

The tension in a diaphragm seal is adjusted by adding or removing diaphragm-to-crankcase gaskets to obtain the specified deflection. For information on handling, cleaning, and replacement of shaft seal assemblies, consult the


METALLIC-COMPOSITION GASKET
c
CARBON RING
NEOPRENE RING
SPRING
b
LAPPED SURFACE
a
CRANKSHAFT
COVER PLATE
METAL WASHER
COMPRESSOR

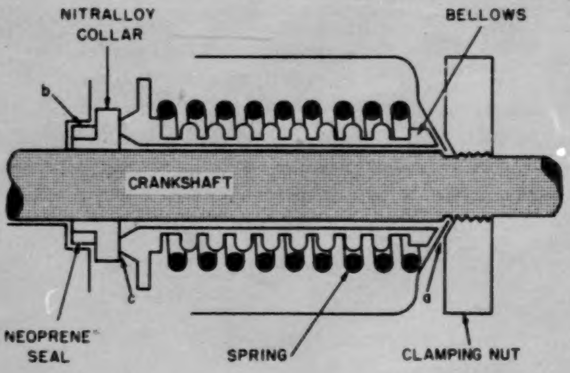
168.7

Figure 18-6.—Rotary seal.

manufacturer's technical manual or the directions enclosed with the new seal.

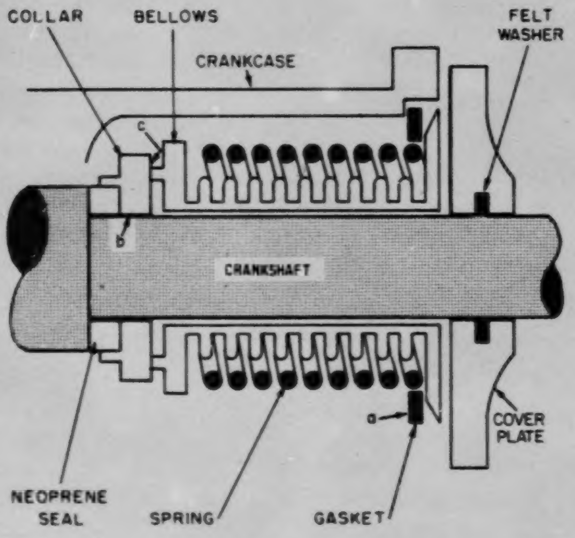
CAPACITY CONTROL SYSTEM:—Most compressors are equipped with an oil-pressure operated automatic capacity control system which "unloads" or cuts cylinders out of operation in accordance with decreases in the refrigeration load requirements of the plant. A cylinder is unloaded by a mechanism that holds the suction valve open so that no gas can be compressed.

Since oil pressure is required to "load" or put cylinders into operation, the compressor will start with all controlled cylinders unloaded. But as soon as the compressor comes up to speed


NITRALLOY COLLAR
BELLOWS
b
CRANKSHAFT
NEOPRENE SEAL
c
SPRING
a
CLAMPING NUT

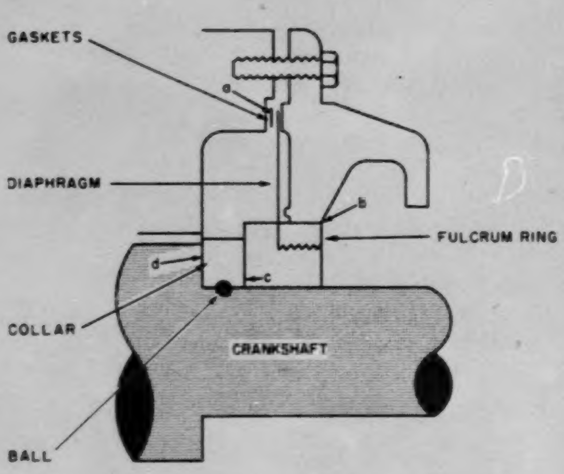
168.9

Figure 18-8.—Rotating bellows seal.


COLLAR
BELLOWS
FELT WASHER
CRANKCASE
c
b
CRANKSHAFT
a
COVER PLATE
NEOPRENE SEAL
SPRING
GASKET

168.8

Figure 18-7.—Stationary bellows seal.


GASKETS
a
DIAPHRAGM
b
FULCRUM RING
d
c
COLLAR
CRANKSHAFT
BALL

168.10

Figure 18-9.—Diaphragm type seal.

and full oil pressure is developed, all cylinders will become operative. After the temperature pulldown period, the refrigeration load imposed on the compressor will decrease and the capacity control system will unload cylinders accordingly. The unloading will result in reduced power consumption. On those applications where numerous cooling coils are supplied by one compressor, the capacity control system will prevent the suction pressure from dropping to the low-pressure cutout setting and, thereby, prevent stopping the compressor before all solenoid valves are closed.

Several different designs of capacity control systems are in use. One of the most common types is shown in figure 18-10. The capacity control system consists of a power element and its linkage for each controlled cylinder, a step control hydraulic relay, and a capacity control valve.

The systems components are all integrally attached to the compressor. The suction or crankcase pressure of the refrigeration plant is sensed by the capacity control valve to control the system. In other words, a change in the refrigeration load on the plant will cause a change in suction pressure; this change in suction pressure will then cause the capacity control system to react according to whether the suction pressure increased or decreased. The working fluid of the system is compressor oil-pump pressure. Compressor oil-pump pressure is metered into the system through an orifice. Once the oil passes the orifice, it becomes the system control oil and does work. Locate the following components on figure 18-10:

(A) Compressor oil pump pressure tap-off
(B) Control oil strainer
(C) Hydraulic relay
(D) Hydraulic relay piston
(E) Unloader power element
(F) Unloader power element piston
(G) Lifting fork
(H) Unloader sleeve
(I) Suction valve
(J) Capacity control valve
(K) Crankcase (suction) pressure sensing point

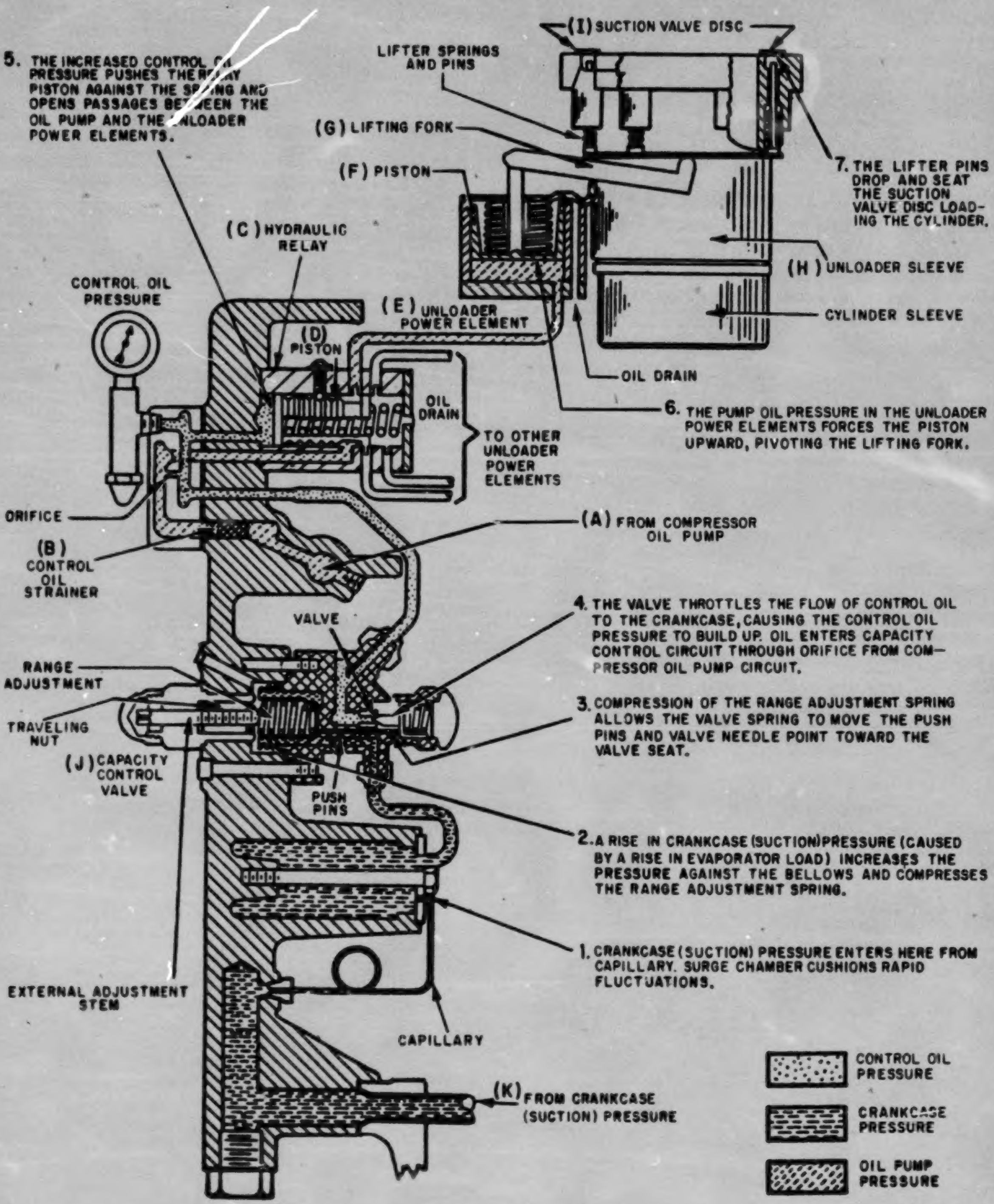
The following functions take place when the compressor is started with a warm load on the refrigeration system.

Compressor oil (A) is pumped through the control oil strainer (B) into the hydraulic relay (C) where the oil flow to the unloader power elements is controlled in steps by the movement of the hydraulic relay piston (D). As soon as pump oil pressure reaches a power element (E), the piston (F) rises, the lifting fork (G) pivots, and the unloader sleeve (H) lowers, permitting the suction valve (I) to seat. The system is governed by suction pressure which actuates the capacity control valve (J). The capacity control valve controls the movement of the hydraulic relay piston by metering the oil bleed from the control oil side of the hydraulic relay back to the crankcase.

Suction pressure increases or decreases according to increases or decreases in the refrigeration load requirements of the plant. After the temperature pulldown period with a subsequent decrease in suction pressure, the capacity control valve moves to increase the control oil bleed to the crankcase from the hydraulic relay. The resulting decrease in control oil pressure within the hydraulic relay allows the piston to be moved by spring action and successively closes oil ports and prevents compressor oil pump pressure from reaching the unloader power elements. As oil pressure leaves a power element, the suction valve rises and that cylinder unloads. With an increase in suction pressure, the above process is reversed, and the controlled cylinders will load in succession. The loading process is detailed in steps 1 through 7 in figure 18-10.

Condenser

The compressor discharges the high-pressure, high-temperature refrigerant vapor to the condenser, where it flows around the tubes through which seawater is being pumped. As the vapor gives up its superheat (sensible heat) to the seawater, the temperature of the vapor drops to the condensation point. As soon as the temperature of the vapor drops to its boiling, or


(I) SUCTION VALVE DISC
LIFTER SPRINGS AND PINS
(G) LIFTING FORK
(F) PISTON
(C) HYDRAULIC RELAY
CONTROL OIL PRESSURE
(E) UNLOADER POWER ELEMENT
(D) PISTON
OIL DRAIN
TO OTHER UNLOADER POWER ELEMENTS
(H) UNLOADER SLEEVE
CYLINDER SLEEVE
OIL DRAIN
ORIFICE
(A) FROM COMPRESSOR OIL PUMP
(B) CONTROL OIL STRAINER
VALVE
RANGE ADJUSTMENT
TRAVELING NUT
(J) CAPACITY CONTROL VALVE
PUSH PINS
EXTERNAL ADJUSTMENT STEM
CAPILLARY
(K) FROM CRANKCASE (SUCTION) PRESSURE
CONTROL OIL PRESSURE
CRANKCASE PRESSURE
OIL PUMP PRESSURE
47.216

5. THE INCREASED CONTROL OIL PRESSURE PUSHES THE RELAY PISTON AGAINST THE SPRING AND OPENS PASSAGES BETWEEN THE OIL PUMP AND THE UNLOADER POWER ELEMENTS.

7. THE LIFTER PINS DROP AND SEAT THE SUCTION VALVE DISC LOADING THE CYLINDER.

6. THE PUMP OIL PRESSURE IN THE UNLOADER POWER ELEMENTS FORCES THE PISTON UPWARD, PIVOTING THE LIFTING FORK.

4. THE VALVE THROTTLES THE FLOW OF CONTROL OIL TO THE CRANKCASE, CAUSING THE CONTROL OIL PRESSURE TO BUILD UP. OIL ENTERS CAPACITY CONTROL CIRCUIT THROUGH ORIFICE FROM COMPRESSOR OIL PUMP CIRCUIT.

3. COMPRESSION OF THE RANGE ADJUSTMENT SPRING ALLOWS THE VALVE SPRING TO MOVE THE PUSH PINS AND VALVE NEEDLE POINT TOWARD THE VALVE SEAT.

2. A RISE IN CRANKCASE (SUCTION) PRESSURE (CAUSED BY A RISE IN EVAPORATOR LOAD) INCREASES THE PRESSURE AGAINST THE BELLOWS AND COMPRESSES THE RANGE ADJUSTMENT SPRING.

1. CRANKCASE (SUCTION) PRESSURE ENTERS HERE FROM CAPILLARY. SURGE CHAMBER CUSHIONS RAPID FLUCTUATIONS.

Figure 18-10.—Capacity control system.

condensing, temperature at the existing pressure, the vapor condenses, giving off its latent heat of vaporization in the process. The refrigerant, now in liquid form, is subcooled slightly below its boiling point (condensation point) at the existing pressure to ensure that it will not flash into vapor.

A water-cooled condenser for an R-12 refrigeration system is shown in figure 18-11. Circulating water is obtained through a branch connection from the firemain or by means of an individual pump taking suction from the sea. The purge connection shown in figure 18-11 is on the refrigerant side; it is used to remove air and other noncondensable gases that are lighter than the R-12 vapor.

Most condensers used for naval refrigeration plants are of the water-cooled type. However, some small units have air-cooled condensers. These consist of tubing with external fins to increase the heat transfer surface. Most air-cooled condensers have fans to ensure positive circulation of air around the condenser tubes.

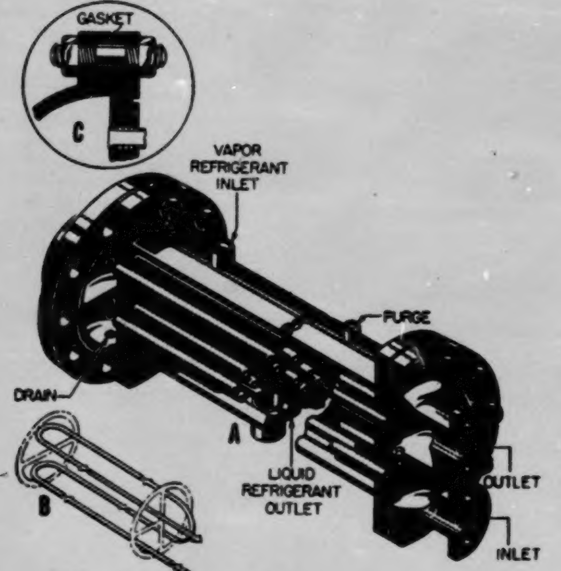


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Figure 18-11.—Water-cooled condenser for R-12 refrigeration system.

Receiver

The receiver, shown in figure 18-12, acts as a temporary storage space and surge tank for the liquid refrigerant which flows from the condenser. The receiver also serves as a vapor seal, to prevent the entrance of vapor into the liquid line to the expansion valve. Receivers may be constructed for either horizontal or vertical installation.

Accessories

In addition to the five main components just described, a refrigeration system requires a number of controls and accessories. The most important of these will be described briefly in the following paragraphs.

DEHYDRATOR.—A dehydrator, or dryer, containing silica-gel or activated alumina, is placed in the liquid refrigerant line between the receiver and the thermostatic expansion valve. In older installations, bypass valves allow the dehydrator to be cut in or out of the system. In newer installations, the dehydrator is installed in the liquid refrigerant line without any bypass arrangement. A dehydrator is shown in figure 18-13.

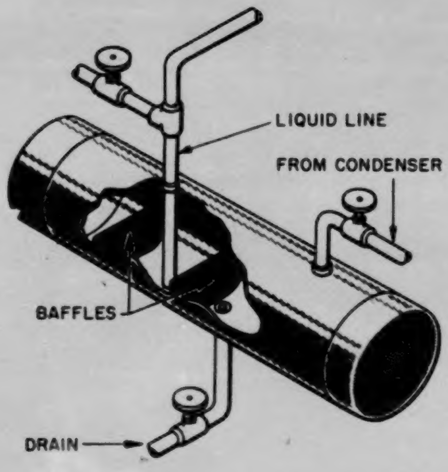

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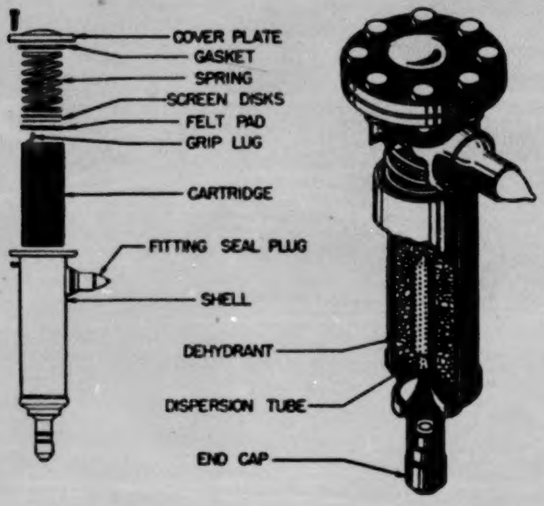
Figure 18-12.—Receiver.


COVER PLATE
GASKET
SPRING
SCREEN DISKS
FELT PAD
GRIP LUG
CARTRIDGE
FITTING SEAL PLUG
SHELL
DEHYDRANT
DISPERSION TUBE
END CAP

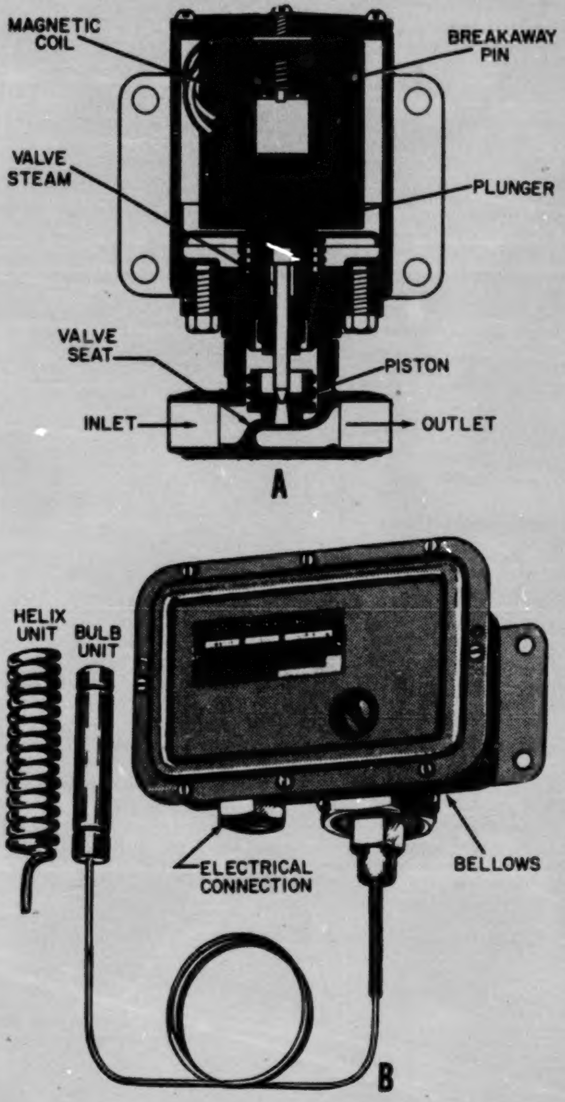
47.97

Figure 18-13.—Refrigerant dehydrator.

MOISTURE INDICATOR.—A moisture indicator is either located in the liquid refrigerant line or built into the dehydrator. The moisture indicator contains a chemically treated element which changes color when there is an increase of moisture in the refrigerant. The color change is reversible and will change back to a DRY reading when the moisture is removed from the refrigerant. Excessive moisture or water will damage the moisture indicator element and turn it gray, which indicates it must be replaced.

SOLENOID VALVE AND THERMOSTATIC CONTROL SWITCH.—A solenoid valve is installed in the liquid line leading to each evaporator. Figure 18-14 shows a solenoid valve and the thermostatic control switch that operates it. The thermostatic control switch is connected by long flexible tubing to a thermal control bulb which is located in the refrigerated space. When the temperature in the refrigerated space drops to the desired point, the thermal control bulb causes the thermostatic control switch to open, thereby closing the solenoid valve and shutting off all flow of liquid refrigerant to the thermostatic expansion valve. When the temperature in the refrigerated space rises above the desired point, the thermostatic control switch closes, the solenoid valve opens, and liquid refrigerant once again flows to the thermostatic expansion valve.

The solenoid valve and its related thermostatic control switch maintain the proper


MAGNETIC COIL
BREAKAWAY PIN
VALVE STEAM
PLUNGER
VALVE SEAT
PISTON
INLET
OUTLET
A
HELIX UNIT
BULB UNIT
ELECTRICAL CONNECTION
BELLOWS
B

47.93:75.120

Figure 18-14.—Solenoid valve and thermostatic control switch.

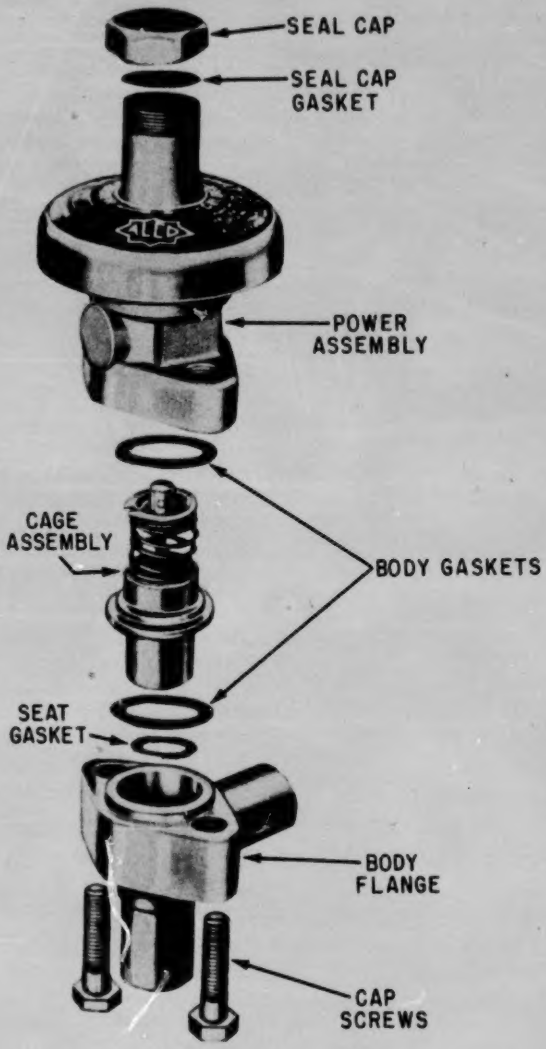
temperature in the refrigerated space. You may wonder why the solenoid valve is necessary if the thermostatic expansion valve controls the amount of refrigerant admitted to the evaporator. Actually, the solenoid valve is not necessary on units that have only one evaporator. In systems that have more than one evaporator, where there is wide variation in load, the solenoid valve provides additional control to prevent the spaces from becoming too cold at light loads.

In addition to the solenoid valve installed in the line to each evaporator, a large refrigeration plant usually has a main liquid line solenoid valve installed just after the receiver. If the compressor stops for any reason except normal suction pressure control, the main liquid solenoid valve closes and prevents liquid refrigerant from flooding the evaporator and flowing to the compressor suction. Extensive damage to the compressor can result if liquid is allowed to enter the compressor suction.

EVAPORATOR PRESSURE REGULATING VALVE.–Whenever several refrigerated spaces of varying temperatures are to be maintained by one compressor, an evaporator pressure regulating valve is installed at the outlet of each evaporator EXCEPT the evaporator in the space in which the lowest temperature is to be maintained. The evaporator pressure regulating valve is set to keep the pressure in the coil from falling below the pressure corresponding to the lowest evaporator temperature desired in that space.

The evaporator pressure regulating valve is used mostly on water coolers, on units where high humidity is required (such as fruit and vegetables stowage spaces) and in installations where two or more rooms are maintained at different temperatures by the use of the same refrigeration unit.

A cross section of a common evaporator pressure regulating valve (commonly called EPR valve) is shown in figure 18-15. The tension of the spring above the diaphragm is adjusted so that when the evaporator coil pressure drops below the desired minimum, the spring will shut the valve.



87.70

Figure 18-15.–Exploded view of typical evaporator pressure regulating valve (EPR).

The EPR valve is not really a temperature control–that is, it does not regulate the temperature in the space. It is only a device to prevent the temperature from becoming too low.

LOW-PRESSURE CUTOUT SWITCH.–The low-pressure cutout switch, or suction pressure control switch, is the control that causes the compressor to go on or off as required for normal operation of the refrigeration plant. This switch is located on the suction side of the compressor and is actuated by pressure changes in the suction line. When the solenoid valves in the lines to the various evaporators are closed, so that the flow of refrigerant to the evaporators is stopped, the pressure of the vapor in the compressor suction line drops quickly. When the suction pressure has dropped to the desired pressure, the low-pressure cutout switch causes the compressor motor to stop. When the temperature in the refrigerated spaces has risen enough to operate one or more of the solenoid valves, refrigerant is again admitted to the cooling coils, and the compressor suction pressure builds up again. At the desired pressure, the low-pressure cutout switch closes, starting the compressor again and repeating the cycle.

HIGH-PRESSURE CUTOUT SWITCH.–A high-pressure cutout switch is connected to the compressor discharge line to protect the high-pressure side of the system against excessive pressures. The design of this switch is essentially the same as that of the low-pressure cutout switch; however, the low-pressure cutout switch is made to CLOSE when the suction pressure reaches its upper normal limit, whereas the high-pressure cutout switch is made to OPEN when the discharge pressure is too high. As mentioned before, the low-pressure cutout switch is the compressor control for normal operation of the plant; the high-pressure cutout switch, on the other hand, is a safety device only and does not have control of compressor operation under normal conditions.

OIL FAILURE SWITCH.–An oil failure switch is provided with high-speed compressors. The switch is designed to prevent operation of the compressor in the event of low oil pressure. The switch is installed with one bellows connected to the oil pressure on the discharge of the compressor oil pump and the other connected to the compressor suction refrigerant pressure. The switch is set to open the electrical circuit and stop the compressor when the oil pressure drops to a low-pressure setpoint and to close the electrical circuit and start the compressor when the oil pressure reaches the reset setpoint.

To start the compressor after it has been stopped and the contacts of the oil failure switch have opened, a time delay mechanism is used with the compressor motor starter. The time delay switch will open 10 to 30 seconds after the compressor motor has been started. The oil pressure normally will be built up in this time interval so that the oil pressure switch will have made contact to keep the compressor motor electrical circuit energized after the time delay switch opens. If the oil pressure has not built up within about 30 seconds after the compressor is started, the contacts of the oil pressure differential switch will not have closed, and the compressor will stop because the time delay relay switch is open.

WATER FAILURE SWITCH.–A water failure switch stops the compressor in the event of failure of the circulating water supply. This is a pressure-actuated switch, generally similar to the low-pressure cutout switch and the high-pressure cutout switch previously described. If the water failure cutout switch should fail to function, the refrigerant pressure in the condenser would quickly build up to the point that the high pressure switch would function.

STRAINER.–Because of the solvent action of R-12, any particles of grit, scale, dirt, or metal that the system may contain are readily circulated through the refrigerant lines. To avoid damage to the compressor from such foreign matter, a strainer is installed in the compressor suction connection.

SPRING-LOADED RELIEF VALVE.–A spring-loaded relief valve is installed in the compressor discharge line as an additional precaution against excessive pressures. The relief valve is set to open at approximately 225 psi; therefore, it functions only in case of failure or improper setting of the high-pressure cutout switch. If the relief valve opens, it discharges high-pressure vapor to the suction side of the compressor.

The type of pressure-actuated control switch used in all of the above installations is of the general type shown in figure 18-16 with its cover removed. (The oil pressure failure switch has two bellows instead of the one shown in the illustration.) These switches are designed to operate at various pressure ranges. Some switches have manual reset buttons to prevent the automatic restoration of power after a pressure failure, such as a high discharge pressure.

WATER REGULATING VALVE.–A water regulating valve controls the quantity of circulating water flowing through the refrigerant condenser. The water regulating valve is actuated by the refrigerant pressure in the compressor discharge line; this pressure acts upon a diaphragm (or, in some valves, a bellows arrangement) which transmits motion to the valve stem.

The primary function of the water regulating valve is to maintain a constant refrigerant condensing pressure. Basically, two variable conditions exist: (1) the amount of refrigerant to be condensed and (2) changing water temperatures. The valve maintains a constant refrigerant condensing pressure by controlling the water flow through the condenser. By sensing the refrigerant pressure, the valve permits only enough water through the condenser to condense the amount of refrigerant vapor coming from the compressor. The quantity of water required to condense a given amount of refrigerant varies with the water temperature. Thus, the flow of cooling water through the condenser is automatically maintained at the rate actually required to condense the refrigerant under varying conditions of load and temperature.

LIQUID STRAINER.–A liquid strainer of the type shown in figure 18-17 is also installed in the liquid line leading to each evaporator; these strainers protect the solenoid valves and the thermostatic expansion valves.

PRESSURE GAGES AND THERMOMETERS.–A number of pressure

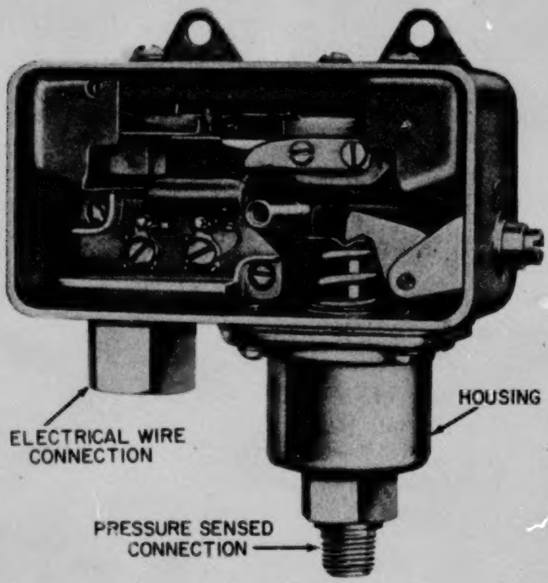


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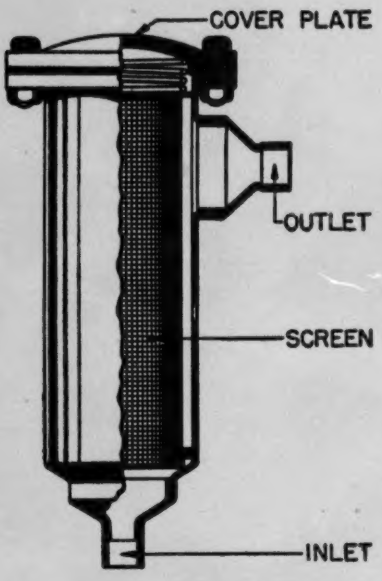
Figure 18-16.–Pressure-actuated control switch.



47.101

Figure 18-17.–Strainer for liquid refrigerant.

gages and thermometers are used in refrigeration systems. Figure 18-18 shows a compound R-12 gage. The temperature markings on this gage show the boiling point (or condensing point) of the refrigerant at each pressure; the gage cannot measure temperature directly. The red pointer is a stationary marker that can be set manually to indicate the maximum working pressure.

A water pressure gage is installed in the circulating water line to the condenser to indicate failure of the circulating water supply.

Standard thermometers of appropriate range are provided for the refrigerant system.

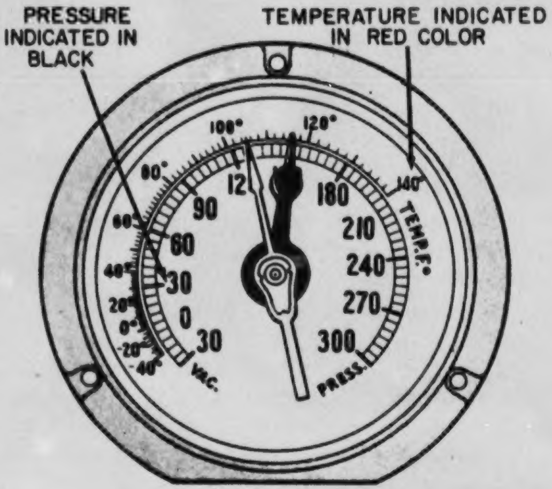
REFRIGERANT PIPING.–Refrigerant piping in modern naval installations is made of copper. Copper is good for this purpose because (1) it does not become corroded by refrigerants; (2) the internal surface of the tubing is smooth enough to minimize friction; and (3) copper tubing is easily shaped to meet installation requirements.

PACKLESS VALVES.–Nearly all hand-operated valves in large refrigeration systems are packless valves of the type shown in figure 18-19. In this type valve the upper part is sealed off from the lower part by a diaphragm. An upward-seating ball check in the lower valve stem makes it possible for the spring to lift the lower stem regardless of pressure differences developed while the valve was closed. Thus, the valve will operate properly regardless of direction of flow. By backseating the valve, the diaphragm can be changed without placing the system or unit out of operation.

OPERATING PROCEDURES FOR AN R-12 SYSTEM

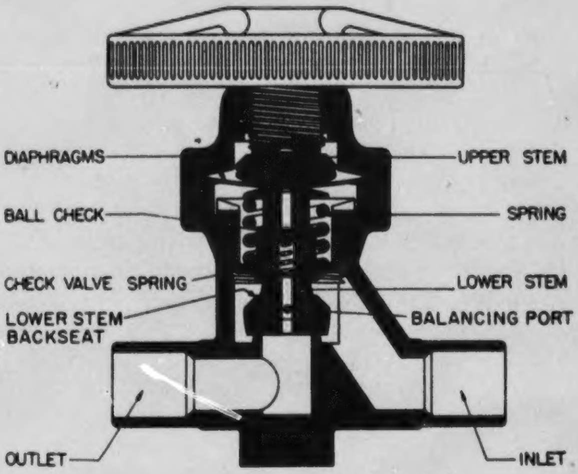
Learning to do all the tasks related to refrigeration system operations will require (1) a good deal of practical experience and (2) attentive observation of the procedures followed by those qualified in refrigeration system operation and maintenance. As an Engineman, your first responsibility with an R-12 system will probably include checking temperatures and pressures, maintaining the plant operating log, detecting symptoms of faulty operation, and checking conditions in the spaces or units being cooled.

The intervals of time between plant inspections will vary depending on the purpose


PRESSURE INDICATED IN BLACK
TEMPERATURE INDICATED IN RED COLOR
100°
120°
80°
60°
40°
20°
0°
-20°
-40°
140°
TEMP.F°
12
90
60
30
0
30
VAC.
180
210
240
270
300
PRESS.

47.102

Figure 18-18.–Compound R-12 pressure gage.


DIAPHRAGMS
UPPER STEM
BALL CHECK
SPRING
CHECK VALVE SPRING
LOWER STEM
LOWER STEM BACKSEAT
BALANCING PORT
OUTLET
INLET

47.103

Figure 18-19.–Packless valve for refrigeration system.

for which the plant is used. The temperatures and pressures throughout the system and the oil level in the compressor crankcase are checked and the results are recorded every hour unless watchstanding instructions specify otherwise. The results of these checks are used to determine whether the plant is operating properly. One of the best methods for checking plant operation is to compare the existing temperatures and pressures with those recorded during a period when the plant was known to be operating properly, under conditions similar to the present conditions.

PRESTARTING CHECKS

The following information on operating procedures is of general nature intended only to familiarize you with plant operation, and should NOT be used for actual operation unless specifically approved for your plant.

1. Open the compressor discharge valve; open all stop valves in the circulating water supply and in the discharge lines for the condenser.
2. Open the condenser refrigerant outlet valve and open the thermal expansion stop valves on the chill and freeze boxes.
3. Start all air circulating fans. On water cooling applications (soda fountains, drinking water coolers, and air conditioning water chillers), admit the water to be cooled, and purge the water circuit of air.
4. If water is taken from the firemain, be sure that the pressure-reducing valve ahead of the water regulating valve is adjusted to provide a water pressure of 35 psi or less. When no pressure-reducing valve is installed, regulate the firemain connection stop valve manually so that the required water pressure ahead of the water regulating valve is maintained.
5. When an individual circulating pump is used to supply condenser circulating water, be sure that all valves, which permit transmission of pump discharge pressure to the water failure switch, are open.
6. If the compressor unit is equipped with an air-cooled condenser, be sure that the airflow passages to the condenser are unobstructed, and that the air circulating fans are clear.
7. Open the compressor discharge-line valve, the stop valve in the line connecting the condenser and the liquid receiver, and the main liquid-line valve.

STARTING THE COMPRESSOR

We must emphasize the need for thoroughness and care at the time the compressor is started. Bent crankshafts, distorted valves, and blown gaskets are a few of the casualties that can occur if proper procedures and applicable precautions are not followed. After accomplishing or checking the items listed under the posted prestarting instructions, proceed as follows:

1. Set the AUTOMATIC-MANUAL selector switch in the MANUAL position.
2. Close the maintaining-contact START button in the pump control circuit to prepare the pump motor for starting.
3. Close the momentary-contact START switch in the compressor control circuit to start the pump motor which also energizes the main line solenoid valve circuit.

As the pump circulates the water, the water failure switch closes automatically and completes the circuit of the compressor-motor contactor coil. When this circuit is closed, the compressor motor starts. In installations that do not have a pump motor and a pump control circuit installed, closing the momentary-contact START switch energizes the compressor control circuit and starts the compressor motor.

4. Start and stop the motor and compressor several times by manual control, to check their operating condition; then, stop the compressor and check the oil level.
5. After determining that the motor and the compressor are in operating condition, crack the suction stop valve and set the controls on AUTOMATIC. This arrangement prevents the pressure in the system from decreasing below that of the atmosphere and drawing air into the compressor.

With the compressor running, open the compressor suction valve slowly, to limit the quantity of suction gas handled by the compressor.

Watch the suction gage as you open the compressor suction valve to ensure that the suction pressure is within the limits of the automatic control low-pressure suction setting. Open the valve at a gradual rate so that there is neither a rapid fluctuation in suction pressure nor a rapid drop of pressure in the compressor crankcase. This will prevent the rapid boiling off of refrigerant from the oil and the carrying of oil into the system. Unusual noise or knocking in the compressor and frosting of crankcase or suction valve are indications that liquid refrigerant is being drawn into the compressor.

6. If lubrication of the compressor is by forced feed, check the pressure on the oil pressure gage.

Unless specific instructions indicate otherwise, the oil pressure should be between 15 and 30 psi above the compressor suction pressure within a few seconds after the compressor is started. If the compressor is designed for automatic capacity control, oil pressure of 50 to 60 psi above suction pressure is required.

7. Be sure the proper quantity of circulating water is flowing through the condenser before the compressor or discharge pressure reaches 125 psi.

8. Open the receiver outlet valve and the main solenoid outlet valve.

OPERATING AN R-12 PLANT IN AUTOMATIC

After the prescribed operating pressures and temperatures have been established with the compressor running in MANUAL, place the selector switch in the AUTOMATIC position. NOTE: A refrigeration compressor should NEVER be left unattended when in the MANUAL mode of operation. The suction-pressure control (low-pressure cutout switch) is connected electrically to start and stop the compressor automatically on the basis of load conditions. If the automatic control valves and switches are in proper adjustment, the operation of the plant, after proper starting, will be entirely automatic.

When the selector switch is set for automatic operation, the water failure switch, the high-pressure switch, or the low-pressure switch will close and energize their respective circuits. Other control devices require the intervention of an operator before the compressor can be restarted. Some high-pressure switches are provided with manual reset devices which must be reset by the operator after the switches have been opened by excessive pressure.

In some installations the supply of condenser cooling water is available either from a centrifugal pump or from the fire and flushing main directly. If cooling water is obtained from the fire and flushing main instead of from the pump, the pump controller switch is opened manually. The water failure switch remains closed regardless of the source of condenser cooling water.

SECURING THE COMPRESSOR

If a compressor is to be secured for only a short time, it is not necessary to pump down the system. The compressor, however, must be pumped down. To do this, first close the compressor suction valve slowly to prevent a too rapid reduction in crankcase pressure. Then, allow the compressor to run until it is stopped by the low-pressure control switch; push the STOP button on the motor-control panel. Next, close the compressor discharge shutoff valve; shut off the water supply to the condensers. Finally, close the main liquid valve downstream from the receiver.

If a refrigeration system is to be secured for an extended time, the system must be pumped down. The pumping-down procedure involves pumping most of the R-12 out of the coils of the evaporator and storing the refrigerant in the receiver. If the quantity of liquid refrigerant contained in the system is in excess of the capacity of the receiver, the surplus liquid must be drawn off into refrigerant drums.

NOTES ON COMPRESSOR OPERATION

An R-12 compressor should not remain idle for an extended period of time. When two or more compressors are installed for a particular plant, the compressors should be operated alternately so that the total operating time on each of the compressors is approximately the same. An idle compressor should be operated at least once a week.

Only one compressor should serve a cooling coil circuit. When compressors are operated in parallel on a common cooling coil circuit, lubricating oil may be transferred from one compressor to another. Such transfer of oil may result in serious damage to all compressors on the circuit.

OPERATING LOG

The operating record of a refrigeration system must be maintained by the personnel on watch. The information recorded in the operating log serves as a guide to the condition of the plant.

MAINTENANCE OF R-12 SYSTEMS

As an Engineman, you will do some of the maintenance jobs required to keep a refrigeration plant operating efficiently. To perform your share of the required maintenance of a refrigeration system, you must be familiar with the proper procedures for the following jobs: defrosting the cooling coils, pumping down a system and checking for noncondensable gases, purging a system of noncondensable gases, using a halide torch to test for refrigerant leaks, checking compressor oil, taking care of V-belts, setting and adjusting refrigeration system controls and safety devices, testing and renewing compressor valves, and care of shaft seals. Most of these maintenance items are covered by the Planned Maintenance System and will be scheduled accordingly.

DEFROSTING OF COOLING COILS

The cooling coils should be defrosted as often as necessary to maintain the effectiveness of the cooling surface. Excessive accumulation of frost on the coils will result in reduced cooling capacity, low compressor-suction pressure, and a tendency for the compressor to short cycle. The maximum permissible time interval between defrosting operations depends on many factors, such as refrigerant evaporating temperature, free-moisture content of supplies placed in the refrigerated space, temperature of refrigerated spaces, frequency of opening of cold-storage compartment doors, and atmospheric humidity. In the average cold-storage refrigeration installation, it is good practice to defrost cooling coils before the average frost thickness reaches 3/16 inch. This is not a hard and fast rule, however; sometimes the frost layer may become appreciably thicker without seriously interfering with plant operation. At other times it may be necessary to defrost more often to maintain satisfactory operation of the plant and proper compartment temperature.

PUMPING DOWN A REFRIGERANT SYSTEM

The pumping-down procedure to be followed will depend on the maintenance to be done. In some cases, the necessary maintenance can be performed on the charged system after a part to be repaired or replaced has been isolated. Generally, it is possible to pump down any part of a charged system (except the condenser, the liquid receiver, and the compressor discharge line) by proper manipulation of cutout valves. When repairs are to be made to a major portion of the system, the refrigerant system must be pumped down to return all refrigerant to the receiver.

If repairs are to be made to the receiver, the condenser, or the compressor discharge line, the entire system must be drained into spare refrigerant drums. However, when a system has valves to isolate the compressor discharge line and condenser and when it is not objectionable to release refrigerant (which may still be trapped in the condenser after the system has been pumped down to the receiver) to the atmosphere, repairs to the compressor discharge line and condenser may be made with this section isolated.

Whenever it is necessary to open a charged system to make repairs or replacements or to clean strainers, the refrigerant pressure within the part of the system to be opened should be pumped down to a pressure slightly above atmospheric (1/2 to 2 psig) before any connections are broken. As a part of the system which contains liquid R-12 is pumped down, its temperature will decrease as a result of the evaporation of the liquid refrigerant. When the temperature of such a part of the system begins to rise to normal again, while the low pressure in the part is maintained, it is reasonably certain that all R-12 liquid within the part has evaporated.

If, in the final evacuation of a part of the system, a pressure of less than 0 psig is reached, sufficient refrigerant should be immediately bled into the evacuated part of the system to raise the pressure to between 1/2 and 2 psig. Connections may then be opened, and repairs, replacement of parts, or other necessary service operations may be accomplished.

When a refrigerant system is opened, the free ends of the refrigerant lines should be temporarily plugged to prevent the entrance of air and dirt. When the connections are remade, one connection is made tight while the other connection is left loose, temporarily, so that the air or other foreign gases in the section of the system which is serviced can be swept out through the free end as this section of the system is slowly purged with refrigerant-gas bled from the charge in the system. The other connection (or connections) is then quickly tightened. Refrigerant lines, oil-charging lines, gage lines, and control lines, although generally of small size and short length, should be purged with refrigerant-gas immediately before they are connected to the system. When connecting lines that have been removed are to be used again, the ends of the lines should be capped to protect the connecting fitting and to ensure that the tube will be clean when it is used again.

When MAJOR REPAIRS are to be made to a major portion of the system or when the system is to be secured for an extended period, the refrigerant system must be pumped down to return all refrigerant to the receiver. Sufficient refrigerant-gas should be retained within the system to create a positive pressure of approximately 2 psig throughout the circuit, except within the compressor-discharge line and the condenser, and between the receiver and the main liquid-line shutoff valve. To pump down the system, close the main liquid-line shutoff valve and the dehydrator-bypass valve (if installed), and open the cooling-coil solenoid valves. Allow the compressor to operate on manual control until the suction pressure reaches approximately 1/2 to 2 psig; then stop the compressor. Repeat the operation until the liquid refrigerant in the circuit has evaporated and the suction pressure remains relatively constant at 1/2 to 2 psig.

During the pump-down period, you can trace the evaporation of liquid refrigerant to the liquid line back to the main liquid-line shutoff valve by the formation of frost and its subsequent melting as the liquid refrigerant is evaporated and superheated. Open the power-supply switch to the compressor; close the compressor suction and discharge shutoff valves. Shut off the water supply to the condenser and drain the condenser water. When the amount of liquid refrigerant contained in the system is in excess of the capacity of the receiver, the surplus liquid refrigerant must be drawn off into separate refrigerant drums.

To drain the refrigerant charge from the system when it is necessary to make repairs to the condenser, the liquid receiver, or the compressor discharge line, or for any other reason, proceed as follows:

1. Start the compressor and pump down the cooling coil and suction-line pressure, with the liquid-line valve at the receiver outlet closed, to the point at which the low-pressure control switch stops the unit.
2. When the compressor is stopped by the low-pressure cutout switch, restart the unit manually and continue the pumping-down

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procedure until the suction pressure reaches approximately 2 psig and stops the compressor. Repeat the operation in periodic cycles until the liquid refrigerant in the circuit has evaporated and the suction pressure remains relatively constant between 1/2 and 5 psig.

3. Close the compressor discharge line valve; close all liquid valves at the cooling coils.

4. Connect an empty R-12 service drum to the refrigerant drain valve. (Before connecting the drum to the R-12 system, cool the drum thoroughly so the refrigerant will drain rapidly into the drum.) Always use a clean R-12 service drum, containing no air or water, so that the drained R-12 is kept in suitable condition for future use.

5. Purge the air out of the line connecting the drain valve and the drum by leaving the connection at the drum valve open as you slowly flush refrigerant through the line and out at the connection; then close the connection. Drain the R-12 into the cooled drum by opening the drain valve and the service drum valve.

6. When the service drum is full, close the drain valve and permit the R-12 liquid in the drain line to evaporate; then, close the service drum valve and disconnect the drum from the system.

7. Weigh the drum while filling, to be certain that it is not overcharged. The net and gross weights are stamped on the drum. (These weights include that of the cast iron protector cap which fits over the cylinder valve.)

CAUTION: NEVER fill a service drum beyond its rated capacity; drum rupture may result from hydraulic pressure upon rise in temperature.

8. Discharge the R-12 vapor that remains in the condenser and receiver to the atmosphere through the purge valve.

TESTING FOR REFRIGERANT LEAKS

Refrigerant leaks mean the loss of the refrigerating effect and loss of refrigerant. Various tests are used to determine the existence of leaks in refrigerant systems. Pressure tests are used after a system has been installed and after extensive repairs or replacement of parts has been made. Pressure tests are made BEFORE the system is charged with refrigerant. Charged systems are tested for leakage with either a halide leak detector, an electronic refrigerant gas detector, or with soapsuds; which of the three methods to be used will depend largely upon the size of the leak and upon the type of space in which the test is to be performed.

As an EN, you will be required to know how to use the detectors and how to use soapsuds to check for the refrigerant leakage.

In addition to tests for leaks that are made at periodic intervals, tests should be made before the compressors are started and at any other time that a shortage of refrigerant in the system is suspected. Unusual operating conditions which indicate a shortage of refrigerant in the system are:

1. High suction-line temperatures.
2. Relatively high crankcase and cylinder temperatures.
3. Excessively high refrigerant temperature in the liquid line.
4. Bubbles in the refrigerant sight-flow indicator.
5. Liquid refrigerant carrying partially through the coil, with considerable superheat at the thermal element.
6. Short cycle or compressor running continuously.
7. Excessive oil seepage at shaft seal connection.
8. Oil seepage at refrigerant-system piping and compressor connections.

A shortage of refrigerant in the system nearly always indicates the presence of leaks. When a shortage of refrigerant is found, the entire system should be tested for leaks by one of the following methods.

Halide Leak Detector

The most positive method of detecting leaks in a refrigerant system is with a halide leak detector which consists essentially of a torch burner, a copper reactor plate, and an exploring hose. (See fig. 18-20.)

CAUTION: Do NOT use a halide or electronic leak detector in any ammunition spaces. Soapsuds is the ONLY method of leak detection to be used in these spaces.

Most detectors use either acetylene gas or alcohol as a fuel. Pressure for detectors that use alcohol is supplied by a pump. If a pump-pressure type alcohol-burning detector is used, be sure that the air pumped into the fuel tank is pure.

Atmosphere suspected of containing R-12 vapor is drawn by injector action through the exploring hose into the torch burner of the detector. Here the air passes over the copper reactor plate, which is heated to incandescence.

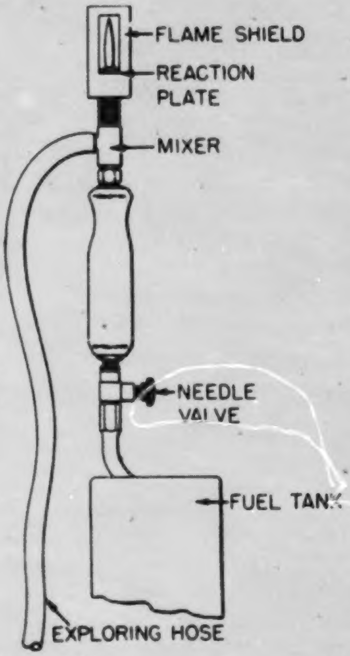

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Figure 18-20.—Halide leak detector.

If there is a minute trace of R-12 present, the color of the torch flame will change from blue (neutral) to green as the R-12 comes in contact with the reactor plate. The shade of green will depend upon the relative amount of R-12 present; a pale green indicates small concentrations and a darker green shows heavier concentrations. Excessive quantities of R-12 will cause the flame to burn with a vivid purple color. Extreme concentrations of R-12 may extinguish the flame by crowding out the oxygen available from the air.

When a leak detector is used, best results are obtained if the following precautions are observed:

1. Be sure that the reactor plate is properly in place.

2. Adjust the flame so that it does not extend beyond the end of the burner. (A small flame is much more sensitive than a large flame. If you experience difficulty in lighting the torch when it is adjusted to produce the necessary small flame, block the end of the exploring hose until the fuel ignites; this will reduce the amount of oxygen drawn in. Then gradually open the hose.)

3. Clean out the exploring tube if the flame continues to have a white or yellow color. (A white or yellow flame indicates that the exploring tube is partially blocked with dirt.)

4. Check to see that air is being drawn into the exploring tube; you can make this check from time to time by holding the end of the tube to your ear.

5. Hold the end of the exploring tube close to the joint being tested to prevent dilution of the sample by stray air currents.

6. Move the end of the exploring hose tube slowly and completely around each joint being tested. (Leak testing cannot be hurried safely. There is a definite time lag between the moment when air enters the exploring tube and the moment it reaches the reactor plate; permit sufficient time for the sample to reach the reactor plate.)

7. If a greenish flame is noted at any time, repeat the test in the same vicinity until the source of the refrigerant is determined.

A halide torch or an electronic refrigerant gas detector is so sensitive that it is useless if the atmosphere is contaminated by excessive leakage of R-12. This is most likely to happen in a small or poorly ventilated compartment. If a compartment is contaminated by R-12 and cannot be ventilated, or if in an ammunition space, the soapsuds test must be used.

Soapsuds Test

In using the soapsuds test, prepare the soap-and-water solution so that it has the consistency of liquid hand soap and will work up a lather on a brush. (The lather will remain wet for a longer period if a few drops of glycerin are added to the solution.)

Apply the lather all the way around the joint; then look carefully for bubbles. If a joint is so located that a part of it is not visible, use a small mirror when inspecting that part.

Remember that it sometimes takes a minute or more for bubbles to appear if the leak is small. Doubtful spots should be lathered and examined a second time.

Always follow a definite procedure in testing for refrigerant leaks, so that you do not miss any joints. If available, use a ship's plan or authorized drawing of the system to "map out" your search. The extra time spent in testing all joints will be justified. Even the smallest leak is not to be considered negligible. However insignificant the leak may seem, it eventually empties the system of its charge to the point of faulty plant operation. Because R-12 is practically odorless, the first indication that leakage exists is the loss of refrigerating effect. A refrigerant system should never be recharged until all leaks are discovered and definitely repaired.

NEVER use oil to test for R-12 leaks. Oil is not reliable because of the capacity of the oil to absorb R-12. If a small leak should exist where oil has been applied, the R-12 will be absorbed by the oil and will show no indication (bubbles) of the leak until the oil is saturated with R-12. Furthermore, if a halide torch is used to test a joint that has been tested previously with oil, the torch will give a false indication because of the R-12 released from the oil.

TESTING FOR AIR AND NONCONDENSABLE GASES

Every reasonable precaution MUST be taken to keep air and noncondensable gases out of a refrigerant system. When air enters the system the condenser must be purged, with a resultant loss of refrigerant. Atmospheric air always contains some moisture, which will enter the system when air does. A refrigerant system must be kept as moisture-free as possible to eliminate such troubles as the freezing of water at the expansion valves, internal oxidation or corrosion of parts, and emulsification or sludging of lubricating oils.

Air and noncondensable gases in a refrigerant system are pumped through the system and are discharged by the compressor into the condenser. These gases are trapped in the condenser by the liquid seal maintained over the receiver outlet. Generally, these gases are lighter than the relatively dense R-12 vapor; they tend to collect, therefore, in the upper part of the condenser when the compressor is stopped. The purge valve for discharging these gases to the atmosphere is located either in the upper part of the condenser shell or in the compressor discharge line above the condenser. While the compressor is in operation, any noncondensable gases in the system are thoroughly mixed with the R-12 vapor. This mixing is caused by the turbulence produced by the rapidly pulsating discharge of refrigerant into the condenser. Therefore, it is not advisable to attempt to purge noncondensable gases from the system while the compressor is in operation. Noncondensable gases in a condenser cause excessive condensing pressures with a resultant loss in plant efficiency.

The best time to check an R-12 system for noncondensable gases is immediately before the compressor starts after a shutdown period. When a condenser is to be checked for noncondensable gases, the gages and thermometers used must be in calibration and the system must have sufficient refrigerant charge so that the liquid refrigerant present in the receiver will seal the liquid line connection.

The following procedure should be followed to check a refrigerant system for noncondensable gases:

1. Close the liquid-line valve.
2. Shut off the compressor and close the suction-line valves.
3. Determine the actual condensing temperature of the refrigerant. A service gage should be installed in the compressor discharge connection if a discharge-pressure gage is not already provided. An approximation of the actual condensing temperature of the refrigerant has been reached when no further decrease is noted in the discharge pressure. (On water-cooled condensers, you can speed up the reduction in pressure by circulating the condenser water until the discharge pressure is reduced.) In most ships the thermometer provided in the liquid line at the receiver indicates the actual condensing temperature. If a thermometer is not installed in an air-cooled condenser application, one should be placed near the condenser to record the ambient temperature at that location. When the temperature of an air-cooled condenser has dropped to the ambient temperature, the reading of the thermometer will approximate the actual condensing temperature.
4. On the compound-pressure gage, read the condensing temperature which corresponds to the condensing pressure registered by the high-pressure gage; the temperature indicated on the temperature scale is the condensing temperature of pure R-12 at the pressure indicated by the gage.
5. Subtract the existing condensing temperature from the condensing temperature of pure R-12 at the existing condenser pressure. If the difference between these two temperatures is more than 5°F, it will be necessary to purge the condenser of noncondensable gases.

If the above test indicates the need for purging, slowly release the noncondensable gases. When a purge valve is not provided, purge the gases by opening the discharge pressure gage connection.

CHECKING COMPRESSOR OIL

If the apparent oil level observed immediately after a prolonged shutdown period is lower than normal, it is almost certain that the actual working oil level is far too low. After you have added a sufficient quantity of oil to raise the apparent oil level to the center of the bull's-eye sight glass, check the actual oil level as follows:

1. Operate the compressor on MANUAL control for at least 1 hour. If the compressor is operating on a water cooler or other coil that is apt to freeze, observe the temperature and interrupt compressor operation as necessary to prevent freezing. Repeat cycling until the total running time (1 hour) is obtained. Then slowly close the suction line stop valve.
2. Stop the compressor. If the compressor is force lubricated, immediately observe the oil level in the sight glass. If the compressor is splash lubricated, turn the flywheel until the crankshaft and connecting rod ends are immersed in the lubricating oil, then check the oil level.

To check the oil level when the compressor has been running on its normal cycle with no abnormal shutdown period, proceed as follows:

1. Wait until the end of a period of operation; if the operation is continuous, wait until the compressor has been in operation at least 1/2 hour, then stop the compressor.
2. As soon as the compressor stops, observe the oil level in the sight glass on force-lubricated compressors. If the compressor is splash lubricated, turn the flywheel until the crankshaft and connecting rod ends are satisfactorily immersed in the lubricating oil; then check the oil level.

Do NOT remove oil from the crankcase because of an apparent high level unless too much oil has been previously added, or unless it is apparent that oil from the crankcase of one compressor of the plant has been inadvertently deposited in the crankcase of another.

However, if the oil level is lower than its recommended height on the glass, a sufficient quantity of oil should be added to obtain the desired level. Do NOT add more oil than is necessary; too much oil can result in excessive oil transfer to the cooling coils.

Adding Oil

There are two common methods of adding oil to a compressor. In one type of installation, a small oil-charging pump is used for adding oil to the compressor crankcase. In another type, a clean, well-dried funnel is used. In either installation, you must be careful to prevent air or foreign matter from entering the compressor.

When performing hourly checks of the compressors, you may observe either no oil in the crankcase or a very low oil level on the sight glass. This indicates that the oil has left the compressor and is circulating in the system; it will be necessary to add oil and operate the system. After the compressor has reclaimed the excessive oil in the system, the excess oil should be drained.

Removing Oil

To remove oil from the compressor crankcase, reduce the pressure in the crankcase to approximately 1 psi by gradually closing the suction line stop valve. Then stop the compressor and close the suction and discharge line valves. Loosen the lubricating oil drain plug near the bottom of the compressor crankcase and allow the required amount of oil to drain out. Since the compressor crankcase is under a slight pressure, do NOT fully remove the drain plug from the compressor; allow the oil to seep out around the threads of the loosened plug. When the desired amount of oil has been removed, tighten the drain plug, open the suction and discharge line valves, and start the compressor. If an oil drain valve is provided in lieu of a plug, you can drain the required amount of oil without pumping down the compressor.

Renewing the Lubricating Oil

When clean copper tubing is used for R-12 systems and when reasonable care has been taken to prevent the entrance of foreign matter and moisture during installation, the oil in the compressor crankcase will probably not become so contaminated that it requires renewal more than once a year. When iron or steel pipe and fittings are used in the R-12 system, a sample of oil from the compressor crankcase should be withdrawn into a clean glass container every 3 months. If the sample shows contamination, all the lubricating oil should be renewed. It is good practice to check the cleanliness of the lubricating oil after each cleaning of the compressor suction scale trap.

CARE OF V-BELTS

Excessive looseness will cause slippage, rapid wear, and deterioration of V-belts. On the other hand, a belt that is too tight will cause excessive wear of both the belt and the main bearing of the compressor. In extreme cases it may cause a bad seal leak. When properly tightened, a belt can be depressed 1/2 to 3/4 inch by the pressure of one finger at a point midway between the flywheel and the motor pulleys.

When replacement of one belt of a multiple V-belt drive is necessary, a complete new set of matched belts should be installed. Belts stretch considerably during the first few hours of operation. Replacement of a single belt will upset the load balance between the new and old belts and will be a potential source of trouble. It is better practice to run the unit temporarily with a defective belt removed than to operate a new belt in conjunction with two or more seasoned belts.

V-belts, motor pulleys, and compressor flywheels should be kept dry and free of oil. Belt dressing should NEVER be used.

SETTING CONTROL AND SAFETY DEVICES

A refrigeration plant cannot operate efficiently and safely unless the control and safety devices are in good working order and set properly. When a new control or safety device is installed in a refrigeration system, it must be adjusted or set to function at pressures or temperatures in accordance with the plant design. Periodic tests and inspections may indicate faulty plant operation that is due to improperly adjusted control or safety devices. As an Engineman, you must know how these devices operate and how to adjust them.

This section contains information on some of the most common types of control and safety devices used by the Navy.

The methods of setting the low-pressure switch, the water failure switch, and the thermostatic switch are similar; however, these switches differ as to operating range, purpose, and setting. Also, the high-pressure switch and the water failure switch are safety devices while the low-pressure switch and the thermostatic switches are control devices. For detailed information, consult *Naval Ships' Technical Manual*, the manufacturer's technical manual, and the PMS for your plant.

High-Pressure Switch

The high-pressure switch has an operating range of 60 to 350 psig and an adjustable differential (difference between the cut-in point and cutout point). Turning the range adjusting screw clockwise raises both the cut-in point and cutout point. Turning it counterclockwise lowers these points. The differential adjustment affects only the cutout point. Turning it clockwise raises the cutout point and turning it counterclockwise lowers the cutout point.

To set the switch, first remove the cover plate. Then the two adjusting screws, one labeled differential, the other labeled range, are easily accessible. Start the compressor and control the discharge pressure by throttling the circulating water through the condenser. Turn the differential screw to its limit counterclockwise and turn the range screw to its limit clockwise. Raise the compressor discharge to about 10 psig above the desired cut-in pressure. Turn the range screw counterclockwise until the contactor in the switch opens, thereby stopping the compressor. When the discharge pressure drops the desired cut-in pressure, turn the range screw clockwise until the contacts close, starting the compressor. The cut-in point is now set. With the compressor running, turn the differential screw to its limit clockwise, then raise the discharge pressure to the desired cutout pressure. Turn the differential screw counterclockwise until the contacts open, stopping the compressor. The cutout point is now set.

Low-Pressure Switch

The low-pressure switch has an operating range of 20 inches of vacuum to 80 psig and an operating differential of 9 psig to 30 psig.

To set the low pressure switch, start the compressor and control the suction pressure by throttling the compressor suction valve. Turn the range and differential adjustment screws counterclockwise. Lower the suction pressure to about 10 psig below the desired cut-in pressure and turn the range screw clockwise until the switch contacts open, stopping the compressor. Allow the suction pressure to rise to the desired cut-in pressure and turn the range screw counterclockwise until the switch contacts close, starting the compressor. The cut-in point is now set. Turn the differential screw to its limit clockwise, throttle the suction valve to lower the suction pressure to the desired cutout pressure. Turn the differential screw counterclockwise until the switch contacts open, stopping the compressor. The cutout point is now set.

Water Failure Switch

The water failure switch should be set to cut in at 15 psig and to cut out at 5 psig. To set the water failure switch, turn the differential screw to its limit counterclockwise for minimum differential since the required differential (difference between cut-in and cutout points) is 10 psig. Throttle the water overboard valve until a pressure of 15 psig is maintained at the condenser inlet. Turn the range screw clockwise until the switch contacts open, then turn the screw counterclockwise slowly until the contacts close. Slowly shut off the water supply, decreasing the pressure. The contacts should open at 5 psig.

Thermostatic Expansion Valve

The thermostatic expansion valve is generally factory set and seldom needs adjustment. The design and construction of expansion valves vary greatly. Figure 18-21 shows a cross-sectional assembly view of a type that is generally used aboard ship. Other designs may have different arrangements for adjustment, sealing, and control.

When the thermostatic expansion valve is operating properly, the temperature at the outlet side of the valve is much lower than that at the inlet side. If this temperature difference does not exist when the system is in operation, the valve seat is probably dirty and clogged with foreign matter.

Once a valve is properly adjusted, further adjustment should not be necessary. The major trouble encountered can usually be traced to a collection of moisture or dirt at the valve seat and orifice. The symptoms of improper valve operation should be carefully analyzed before concluding that the valve is out of adjustment. Once a valve is properly adjusted, additional adjustment should not be necessary unless changes are made to the cooling coil arrangement or thermal element location.

By means of a gear and screw arrangement, the thermostatic expansion valve is adjusted to maintain a superheat ranging from approximately 4° to 12°F at the cooling coil outlet. The proper superheat adjustment varies with the design and service-operating conditions of the valve and the design of the particular plant. Increased spring pressure increases the degree of superheat at the coil outlet and decreased pressure has the opposite effect. Many thermostatic expansion valves are initially adjusted by the manufacturer to maintain a predetermined degree of superheat, and no provision is made for further adjustments in service.

If expansion valves are adjusted to give a high degree of superheat at the coil outlet or if the valve is stuck shut, the amount of refrigerant

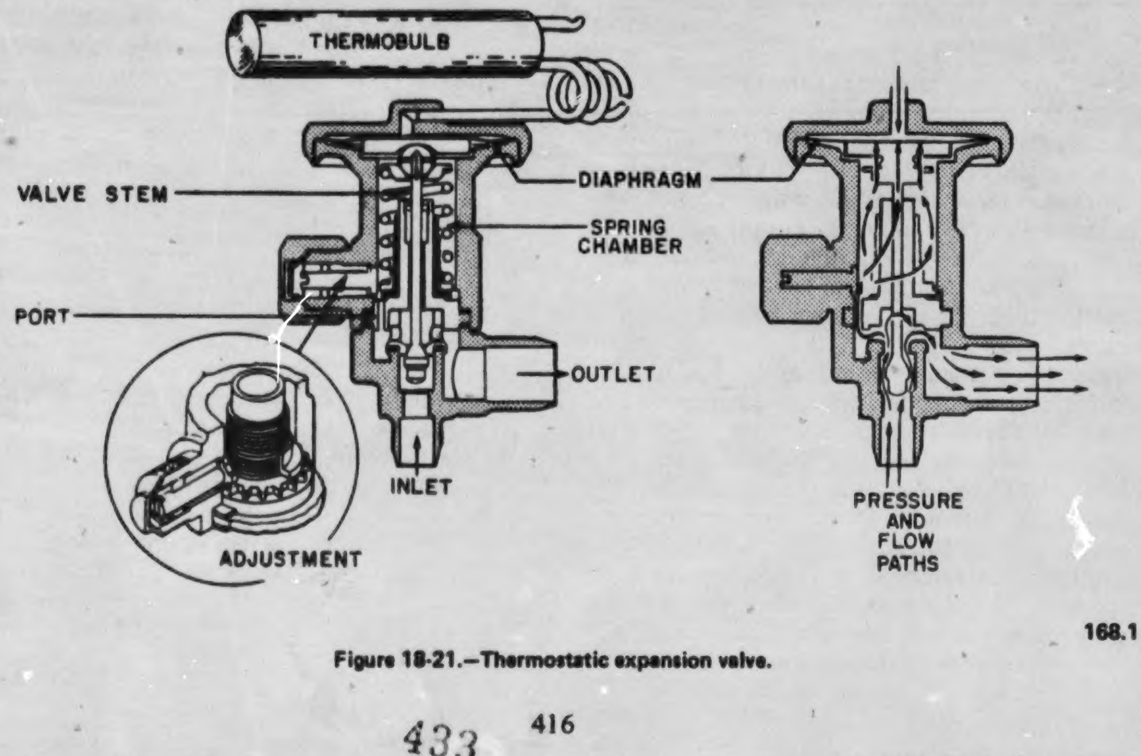

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Figure 18-21.—Thermostatic expansion valve.

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admitted to the cooling coil will be reduced. With an insufficient amount of refrigerant, the coil will be "starved" and will operate at a reduced capacity. Compressor lubricating oil carried with the refrigerant may tend to collect at the bottom of the cooling coils, thus robbing the compressor crankcase and providing a condition whereby slugs of lubricating oil may be drawn back to the compressor. If the expansion valve is adjusted for a too low degree of superheat or if the valve is stuck open, liquid refrigerant may flood from the cooling coils back to the compressor. If the liquid collects at a low point in the suction line or coil and is drawn back to the compressor intermittently in slugs, there is danger of injury to the moving parts of the compressor.

In general, the expansion valves for air conditioning and water cooling plants (high-temperature installations) must be adjusted for higher superheat than the expansion valves for cold storage refrigeration and ship's service store equipment (low-temperature installations).

Water Regulating Valve

The water regulating valve should be adjusted to maintain a compressor discharge pressure of approximately 125 psig. To raise the valve opening point, turn the adjusting nuts clockwise, increasing tension on the main spring. Increasing main spring tension increases the amount of pressure required to open the valve. Turning the adjusting nuts counterclockwise decreases the main spring tension, thereby decreasing the amount of pressure required to open the valve. If the ambient temperature is high, pressure (gas) in the compressor discharge line and the condenser may remain high and cause the water regulating valve to partly open when the compressor is idle. In such instances, the point of valve opening should be raised just enough to cause the valve to close during compressor shutdown.

The valve can be flushed by opening it with an outside force; a screwdriver or similar tool may be used to force the spring yoke.

Thermostatic Switch

The thermostatic switch which operates the solenoid valve is similar to the low-pressure switch. Tubing connects a bellows in the thermostatic switch to a thermobulb in the compartment being cooled. The thermobulb and tubing are charged with R-12 or some other volatile liquid. Temperature changes in the refrigerated compartment cause corresponding pressure changes of the actuating medium in the thermobulb. These pressure changes are transmitted to the thermostatic switch, through the connecting tubing. To set or adjust the cut-in and cutout points of the thermostatic switch, the same procedure is used as in setting and adjusting the low-pressure switch.

Automatic Reducing Valve

When condenser circulating water is obtained from the firemain, the pressure must be reduced. For this pressure reduction, an automatic reducing valve is installed in the branch line leading from the firemain to the condenser. The reducing valve is installed just ahead of the regulating valve. The outlet pressure can be varied by turning the adjusting screw, which is located under the cap. Turning the adjusting screw clockwise increases the pressure applied by the spring to the top of the diaphragm, thus opening the valve wider and increasing the outlet pressure. Turning the adjusting screw counterclockwise decreases the spring pressure on the top of the diaphragm, thus tending to decrease the discharge pressure.

TESTING AND RENEWING COMPRESSOR DISCHARGE AND SUCTION VALVES

An R-12 compressor SHOULD NOT BE OPENED for valve inspection or replacement until it has been determined that the faulty operation of the system is caused by improper functioning of the valves. Faulty compressor valves may be indicated by either an increase in discharge temperature or decrease in the normal compressor capacity. Either the compressor will fail to pump at all or the suction pressure cannot be pumped down to the designed value, and the compressor will run for abnormally long intervals (or even continuously). If the compressor shuts down for short periods (short cycles), the compressor valves may be leaking.

If the refrigeration plant is not operating satisfactorily, it will be best to first shift the compressor and then check the operation of the plant. If the operation of the plant is satisfactory when the compressors have been shifted, this indicates that the trouble was with the compressor.

The compressor discharge valves may be tested by pumping down the compressor to 2 psig, then stopping the compressor, and quickly closing the suction and discharge line valves. If the discharge pressure drops at a rate in excess of 3 psi per minute and the crankcase suction pressure rises, there is evidence of compressor discharge valve leakage. If it is necessary to remove the discharge valves with the compressor pumped down, break the connection to the discharge pressure gage to release discharge pressure on the head. Then remove the compressor top head and discharge valve plate, being careful not to damage the gaskets.

If the discharge valves are defective, the entire discharge valve assembly should be replaced. Any attempt to repair the valve would probably involve relapping and would require highly specialized equipment. Except in an emergency, such repair should never be undertaken aboard ship.

You can check the compressor internal suction valves for leakage by performing these steps:

1. Start the compressor by using the MANUAL control switch on the motor controller.

2. Close the suction line stop valve gradually to prevent violent foaming of the compressor crankcase lubricating oil charge.

3. Pump a vacuum of approximately 20 inches of mercury. If this vacuum can be readily obtained, the compressor suction valves are satisfactory.

Do not expect the vacuum to be maintained after the compressor stops because R-12 being released from the crankcase oil will cause the pressure to rise. Do NOT attempt to check compressor suction valve efficiency of new R-12 units until after the compressor has been in operation for at least 3 days. It may be necessary for the valves to wear in.

However, if any of the compressor valves are defective, the compressor should be pumped down, opened, and the valves inspected. Defective valves or pistons should be replaced with spare assemblies.

SHAFT SEALS

The first indication of shaft seal failure is excessive oil leaking at the shaft. When the seal requires replacement or when signs of abnormal wear or damage to the running surfaces are present, a definite reason for the abnormal conditions exists and an inspection should be made. It is very important to locate and correct the trouble, or the failure will recur.

Seal failure is very often the result of faulty lubrication, usually due to the condition of the crankcase oil. Dirty or acidic oil is generally caused by one or both of the following conditions:

1. Dirt or foreign material in the system or system piping. Dirt frequently enters the system at the time of installation. After a period of operation, any foreign material present in the system will always accumulate in the compressor crankcase, tending to concentrate in the oil chamber surrounding the shaft seal. When the oil contains grit, it is only a matter of time until the highly finished running faces become damaged, causing failure of the shaft seal. At any time foreign material is found in the lubricating oil, the entire system (piping, valves, and strainers) should be cleaned thoroughly.

2. Moisture is frequently the cause of an acid condition of the lubricating oil. Oil in this condition will not provide satisfactory lubrication and will promote failure of the compressor parts. If the presence of moisture is suspected, a dryer should be used when the compressor is put into operation.

Removing Shaft Seal

In the event a shaft seal must be repaired or renewed, the procedure is generally as follows:

If the seal is broken to the extent that it permits excessive oil leakage, do not attempt to pump the refrigerant out of the compressor because air (containing moisture) will be drawn into the system through the damaged seal. Moisture in the air may cause expansion valves to freeze. If oil is leaking excessively, close the compressor suction and discharge valves and relieve the pressure to the atmosphere by loosening a connection on the compressor discharge gage line. If the condition of the seal permits, pump down the compressor as explained earlier in this chapter.

Next, drain and measure the oil from the compressor crankcase so that an equal amount can be replaced. Since the oil contains refrigerant, it will foam while being drained. The oil drain valve or plug should be left open while you are working on the seal so that refrigerant escaping from the oil remaining in the crankcase will not build up pressure and unexpectedly blow out the seal while it is being removed.

Remove the compressor flywheel (or coupling) and carefully remove the shaft seal assembly. If the assembly cannot be readily removed, build up a slight pressure in the compressor crankcase by slightly opening the compressor suction valve, taking the necessary precautions to support the seal to prevent it from being blown from the compressor and damaged.

Installing Shaft Seal

When replacement is made, the entire seal assembly should be replaced. The parts should be cleaned and replaced in accordance with the manufacturer's instructions.

Wipe the shaft clean with a cloth. Do NOT use a dirty or lint-bearing cloth. Unwrap the seal, being careful not to touch the bearing surfaces with your hands. Rinse the seal in an approved solvent and allow it to air-dry. (Do NOT wipe the seal dry.) Dip the seal in clean refrigerant oil. Insert the assembly in accordance with the manufacturer's instructions and bolt the seal cover in place, tightening the bolts evenly. Replace the flywheel and belts and add the amount of oil removed; then test the unit for leaks by opening the suction and discharge valves and using a halide leak detector.

CHARACTERISTICS OF REFRIGERANTS

Pure R-12 (CCl_2F_2) is colorless. In concentrations of less than 20% by volume in air, R-12 is odorless; in higher concentrations, its odor resembles that of carbon tetrachloride. It has a boiling point of -21°F at atmospheric pressure. At ordinary temperatures R-12 is a liquid when under a pressure of approximately 70 to 75 psig.

Mixtures of R-12 vapor and air, in all proportions, are nonirritating to the eyes, nose, throat, and lungs. The refrigerant will not contaminate or poison foods or other supplies with which it may come in contact. The vapor is nonpoisonous; it will not support respiration, however, and it produces mild euphoria when it is inhaled in sufficient quantities. If R-12 concentration becomes excessive, unconsciousness or even death may result due to lack of oxygen to the brain. In view of R-12's low boiling point at atmospheric pressure, you must always protect your eyes from contact with liquid R-12; the liquid will freeze the tissues of the eyes. ALWAYS WEAR GOGGLES IF YOU ARE TO BE EXPOSED TO R-12.

R-12 in either a liquid or vapor state is nonflammable and nonexplosive. R-12 will not corrode the metals commonly used in refrigerating systems.

One REMOTE health hazard could exist if leakage of a large amount of R-12 vapor came in direct contact with an open flame of high temperature (about 1,000°F) and decomposed. To be a health hazard, the leakage of R-12 must be within a confined and poorly ventilated space and the vapor must come in contact with a

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high-temperature flame. When these conditions exist, however, the products of decomposition are pungent and irritating, rendering them noticeable even when present only in minute quantities; ample warning is available before concentrations dangerous to health are reached.

R-12 is a stable compound capable of undergoing (without decomposition) the physical changes required of it in refrigeration service. It is an excellent solvent and has the ability to loosen and remove all particles of dirt, scale, and oil with which it comes in contact within a refrigerating system.

R-22 ($CHClF_2$) and R-11 (CCl_3F) are colorless, nonexplosive, nonpoisonous refrigerants with many properties similar to those of R-12.

SAFETY PRECAUTIONS

Refrigerants are furnished in cylinders for use in shipboard refrigeration systems. The following precautions MUST BE OBSERVED in the handling, use, and storage of these cylinders:

1. NEVER drop cylinders nor permit them to strike each other violently.
2. NEVER use a lifting magnet or a sling (rope or chain) when handling cylinders. A crane may be used if a safe cradle or platform is provided to hold the cylinders.
3. Caps provided for valve protection must be kept on cylinders except when the cylinders are being used.
4. Whenever refrigerant is discharged from a cylinder, the cylinder should be weighed immediately and the weight of the refrigerant remaining in the cylinder should be recorded.
5. NEVER attempt to mix gases in a cylinder.
6. NEVER put the wrong refrigerant into a refrigeration system! No refrigerant except the one for which a system was designed should ever be introduced into the system. Check the equipment nameplate or the manufacturer's technical manual to determine the proper refrigerant type and charge. Putting the wrong refrigerant into a system may cause a violent explosion.
7. When a cylinder has been emptied, close the cylinder valve immediately to prevent the entrance of air, moisture, or dirt. Also, be sure to replace the valve protection cap.
8. NEVER use cylinders for any purpose other than their intended purpose. Do NOT use them as rollers, supports, etc.
9. Do NOT tamper with the safety devices in the valves or cylinders.
10. Open cylinder valves slowly. NEVER use wrenches or other tools except those provided by the manufacturer.
11. Be sure that the threads on regulators or other connections are the same as those on the cylinder valve outlets. NEVER force connections that do not fit.
12. Regulators and pressure gages provided for use with a particular gas must NOT be used on cylinders containing other gases.
13. NEVER attempt to repair or alter cylinders or valves.
14. NEVER fill R-12 cylinders beyond 85% capacity.
15. Store cylinders in a cool, dry place, in an UPRIGHT position. If the cylinders are exposed to excessive heat, a dangerous increase in pressure will occur. If cylinders must be stored in the open, ensure that they are protected against extremes of weather. NEVER allow a cylinder to be subjected to a temperature above 125°F.
16. NEVER allow R-12 to come in contact with a flame or red-hot metal! When exposed to excessively high temperatures, R-12 breaks down into PHOSGENE gas, an extremely POISONOUS substance.

Because R-12 is such a powerful freezing agent that even a very small amount can freeze the delicate tissues of the eye, causing permanent damage, it is essential that goggles be worn by all personnel who may be exposed to a refrigerant, particularly in its liquid form. If refrigerant does get into the eyes, the person suffering the injury should receive IMMEDIATE medical treatment to avoid permanent damage to the eyes. In the meantime, put drops of clean olive oil, mineral oil, or other nonirritating oil in the eyes, and MAKE SURE that the person does NOT rub his eyes. CAUTION: Do NOT use anything except clean, nonirritating oil for this type of eye injury.

If R-12 comes in contact with the skin, it may cause frostbite. This injury should be treated as any other cause of frostbite. Immerse the affected part in a warm bath for about 10 minutes, then dry carefully. Do NOT rub or massage the affected area.

Although R-12 is generally classed as nontoxic, it IS dangerous in high concentrations such as might occur from excessive R-12 leakage in a confined or poorly ventilated space due to lack of oxygen. If a person should be overcome by R-12, move him or her IMMEDIATELY to a well-ventilated place and get medical attention at the earliest opportunity. Watch the victim's breathing; if there are no signs of breathing, begin artificial respiration.

CHAPTER 19

AIR CONDITIONING

Air conditioning is a field of engineering dealing with the design, construction, and operation of equipment used in establishing and maintaining desirable indoor air conditions. It is the science of maintaining the atmosphere of an enclosure at any required temperature, humidity, and purity. As such, air conditioning involves the cooling, heating, dehumidifying, ventilating, and purifying of air.

This chapter covers the principal factors involved in the conditioning of air; the type of equipment used in ventilating, cooling, and heating the air; and general information concerning the maintenance of air conditioning equipment. Additional information may be obtained from chapter 510 of the *NAVSHIPS' Technical Manual.*

PURPOSES OF AIR CONDITIONING AND RELATED FACTORS

One of the chief purposes of air conditioning aboard ship is to keep the crew alert and physically fit. The human body cannot long maintain a high level of efficiency under adverse air conditions. Many different types of compartments must be kept at a prescribed temperature with proper circulation and must contain proper moisture content, correct proportion of oxygen, and no more than an acceptable level of air contamination (dust, airborne, dirt, etc).

The comfort and fitness of the crew is only one purpose of air conditioning. Mechanical cooling or ventilation must also be provided in AMMUNITION SPACES to prevent deterioration of ammunition components; in GAS STORAGE SPACES to prevent excessive pressure buildup in containers and contamination in the space caused by gas leakage; and in ELECTRICAL/ELECTRONIC EQUIPMENT SPACES to maintain the ambient (encompassing) temperature and humidity as specified for the equipment.

The principal factors in connection with achieving the objectives of air conditioning are humidity, heat of air, temperature, body heat balance, the effect of air motion, and the sensation of comfort.

HUMIDITY

Humidity is the vapor content of the atmosphere, and it has a great influence on human comfort. The common expression, "It isn't the heat, its the humidity," indicates an awareness of the discomfort produced by moisture-laden air in hot weather. Extremely low moisture content also has undesirable effects on the human body. The measurement and control of the moisture content of the air is an important phase of air conditioning engineering. To understand this phase of air conditioning engineering, you should become familiar with the meaning of saturated air, absolute and specific humidity, and relative humidity.

Saturated Air

Air can hold varying amounts of water vapor, depending on its temperature (at a given atmospheric pressure). As temperature rises, the amount of moisture that the air can hold increases (if there is no change in atmospheric pressure). But for every temperature there is a definite limit to the amount of moisture that the air is capable of holding. When air contains the maximum amount of moisture that it can hold at a specific temperature and pressure, it is said to be saturated.

The saturation point is usually called the DEWPOINT. If the temperature of saturated air falls below its dewpoint, some of the water vapor in the air must condense to water. The dew that appears on decks and bulkheads in the early morning, when there is a drop in temperature, is such a condensation. The "sweating" of cold water pipes is the result of water vapor from the relatively warm air condensing on the cold surface of the pipes.

Absolute and Specific Humidity

The amount of water vapor in the air is expressed in terms of weight of the moisture. The weight is usually given in grains (7,000 grains equal 1 pound). Absolute humidity is the weight in grains of water vapor per cubic foot of air. Specific humidity is the weight in grains of water vapor per pound of air. (The weight of water vapor refers only to moisture in the vapor state, and not in any way to the moisture that may be present in the liquid state, such as rain or dew.)

Relative Humidity

Relative humidity is the ratio of the weight of water vapor in a sample of air to the weight of water vapor the same sample of air would contain if saturated at the existing temperature. This ratio is usually stated as a percentage. For example, when air is fully saturated, its relative humidity is 100%. When air contains no moisture at all, its relative humidity is 0%. If air is half saturated, the relative humidity is 50%.

Insofar as humidity is concerned, the deciding factor in human comfort is the relative humidity, not the absolute or specific humidity.

Just as heat travels from regions of higher temperature to regions of lower temperature, moisture always travels from regions of higher vapor pressure to regions of lower vapor pressure. If the air above a liquid is saturated, the two are in equilibrium (balance) and no moisture can travel from the liquid to the air; that is, the liquid cannot evaporate. If the air is only partially saturated, some moisture can travel to the air; that is, some evaporation can take place.

If the specific humidity of the air is 120 grains per pound, 120 grains is the actual weight of the water vapor in the air. When the temperature of the same air is 76°F (24.4°C) and the relative humidity is nearly 90%, the air is nearly saturated. At such a relative humidity, the body may perspire freely, but the perspiration does not evaporate rapidly; thus a general feeling of discomfort results.

However, when the temperature of the same air is 86°F (30°C), the relative humidity would then be only 64%. That is, although the absolute amount of moisture in the air is the same, the relative humidity is lower, because at 86°F (30°C) the air is capable of holding more water vapor than it can hold at 76°F (24.4°C). The body is now able to evaporate its excess moisture and the general feeling is much more agreeable, even though the temperature of the air is 10°F (5.6°C) higher. (The cooling effect on the body is brought about by the absorption of latent heat during the evaporating process.)

In both examples, the specific humidity is the same, but the ability of the air to evaporate liquid is quite different at the two temperatures. The ability to evaporate moisture is directly indicated by the relative humidity. This is the reason that the control of relative humidity is of extreme importance in air conditioning.

HEAT OF AIR

The heat of air is considered from three standpoints–sensible, latent, and total heat.

SENSIBLE HEAT is the amount of heat which, when added to or removed from air, changes the temperature of the air. Sensible heat changes can be measured by the common (or a dry-bulb) thermometer.

Air always contains some water vapor. Any water vapor in the air contains the LATENT HEAT OF VAPORIZATION. (Remember that the amount of latent heat present has no effect upon the temperature of the air, and it cannot be measured with a dry-bulb thermometer.)

Any mixture of dry air and water vapor contains both sensible and latent heat. The sum of the sensible heat and the latent heat in any sample of air is called the TOTAL HEAT of air.

TEMPERATURES

To test the effectiveness of air conditioning equipment and to check the humidity of a space, two different temperatures are considered. These are the dry-bulb and wet-bulb temperatures.

Measurement of Temperatures

The DRY-BULB TEMPERATURE is the temperature of sensible heat of the air, as measured by an ordinary thermometer. Such a thermometer in air conditioning engineering is referred to as a dry-bulb thermometer because its sensing bulb is dry, in contrast with the wet-bulb type described next.

The WET-BULB TEMPERATURE is best explained by a description of a wet-bulb thermometer. It is a dry-bulb thermometer with a loosely woven cloth sleeve or wick placed around its bulb which is then wet with distilled water. The water in the sleeve or wick is caused to evaporate by a current of air (see next paragraph) at high velocity. This evaporation withdraws heat from the thermometer bulb, lowering the temperature by several degrees. The difference between the dry-bulb and the wet-bulb temperature is called the wet-bulb depression. When the wet-bulb temperature is the same as the dry-bulb temperature, air is saturated (that is, when evaporation cannot take place). The condition of saturation is unusual, however, and a wet-bulb depression is normally expected.

The wet-bulb and dry-bulb thermometers are usually mounted side by side on a frame that has a handle or short chain attached so that the thermometers can be whirled in the air, thus providing a high-velocity air to promote evaporation. Such a device is known as a SLING PSYCHROMETER. When using a sling psychrometer, whirl it rapidly, at least four times per second. Observe the wet-bulb temperature at intervals. The point at which there is no further drop in temperature is the wet-bulb temperature for that space.

MOTORIZED PSYCHROMETERS have a small motor-driven fan powered by dry cell batteries. Motorized psychrometers are generally preferred and are gradually replacing sling psychrometers.

Relationships Between the Temperatures

The definite relationships between the three temperatures—dry-bulb, wet-bulb, dewpoint—should be clearly understood.

1. When the air contains some moisture but is not saturated, the dewpoint temperature is lower than the dry-bulb temperature, and the wet-bulb temperature lies between them.
2. As the amount of moisture in the air increases, the difference between the dry-bulb temperature and wet-bulb temperature will become less.
3. When the air is saturated, all three temperatures will be the same.

BODY HEAT BALANCE

Ordinarily the human body remains at a fairly constant temperature of 98.6°F (37°C). It is very important that this body temperature be maintained and, since there is a continuous heat gain from internal body processes, there must also be a continuous outgo to maintain body heat in balance. Excess heat must be absorbed by the surrounding air or lost by radiation. As the temperature and humidity of the environment vary, the body automatically regulates the amount of heat that it gives off. However, the body's ability to adjust to varying environmental conditions is limited. Furthermore, although the body may adjust to a certain (limited) range of atmospheric conditions, it does so with a distinct feeling of discomfort. The discussion which follows will help you understand how atmospheric conditions affect the body's ability to maintain a heat balance.

Body Heat Gains

The body gains heat (1) by radiation, (2) by convection, (3) by conduction, and (4) as a by-product of physiological processes that take place within the body.

The heat gain by radiation comes from our surroundings but, since heat always travels from regions of higher temperature to regions of lower temperature, the body receives heat from those surroundings that have a temperature higher than body surface temperature. The greatest source of heat radiation is the sun. Sources of indoor heat radiation are heating devices, operating machinery, hot steam piping, etc.

The heat gain by convection comes from currents of heated air only. Such currents of air may come from a galley stove or an engine.

The heat gain by conduction comes from objects with which the body, from time to time, is in contact.

Most body heat comes from within the body itself. Heat is produced continuously inside the body by the oxidation of foodstuffs and by other chemical processes, by friction and tension within the muscle tissues, and by other causes as yet not completely identified.

Body Heat Losses

There are two types of body heat losses: loss of sensible heat and loss of latent heat. Sensible heat is given off by (1) radiation, (2) convection, and (3) conduction. Latent heat is given off in the breath and by evaporation of perspiration.

The body is usually at a higher temperature than that of its surroundings and, therefore, radiates heat to bulkheads, decks, and equipment. This action is called heat radiation loss. The temperature of the air does not influence this radiation, except as it may alter the temperature of such surroundings.

Heat loss by convection occurs when the heat is carried away from the body by convection (heated) currents, both by the air coming out of the lungs and by exterior air currents.

Heat loss by conduction is caused by bodily contact with colder objects or substances. Since the body is usually at a higher temperature than that of its surroundings, it gives up heat by conduction through physical contact with its surroundings.

When the air temperature and relative humidity are not too high and when the body is not too active, the body gets rid of its excess heat by radiation, convection, conduction, and a slight amount of perspiration. When engaged in work or exercise, the body develops much more internal heat, and perspiration increases. If the relative humidity is low, perspiration rapidly evaporates. As the perspiration evaporates, the body loses additional heat (latent heat of vaporization). However, if the relative humidity of the air is high, the moisture cannot evaporate, or it does so at a slow rate; hence, the excess heat cannot be removed fast enough by evaporation and discomfort follows.

The amount of heat given off by the body varies according to the body's activity. When seated at rest, the average adult gives off about 95 calories or 380 Btu per hour. Doing routine work in a ship, an adult gives off an average of 126 to 151 calories or 500 to 600 Btu per hour.

During light work in a ship, particularly on a submarine, research has shown that the total amount of body heat loss is divided as follows: About 45% by radiation, 30% by convection and conduction, and 25% by evaporation.

EFFECT OF AIR MOTION

In perfectly still air, the layer of air around a body absorbs the sensible heat given off by the body and increases in temperature. The layer of air also absorbs some of the water vapor given off by the body, thus increasing in relative humidity. This means the body is surrounded by an envelope of moist air which is at a higher temperature and relative humidity than the ambient air. Therefore, the amount of heat that the body can lose to this envelope is less than the amount it can lose to the ambient air. When the air is set in motion past the body, the envelope is continually being removed and replaced by the ambient air, thereby increasing the rate of heat loss from the body. When the increased heat loss improves the heat balance, the sensation of a "breeze" is felt; when the increase is excessive, the rate of heat loss makes the body feel cool and the sensation of a "draft" is felt.

SENSATION OF COMFORT

From the foregoing discussion, it is evident that the three factors—temperature, humidity, and air motion—are closely interrelated in their effects upon comfort and health of personnel aboard ship. In fact, a given combination of temperature, humidity, and air motion will produce the same feeling of warmth or coolness as a higher or lower temperature in conjunction with a compensating humidity and air motion. The term given to the net effect of these three factors is EFFECTIVE TEMPERATURE. Effective temperature cannot be measured by any instrument, but can be found on a special psychrometric chart when the wet-bulb and dry-bulb temperatures and the air velocity are known.

Although all of the combinations of temperature, relative humidity, and air motion of a particular effective temperature may produce the same feeling of warmth or coolness, they are NOT all equally comfortable. Relative humidity below 15% produces a parched condition of the mucous membranes of the mouth, nose, and lungs and increases susceptibility to disease germs. Relative humidity above 70% causes an accumulation of moisture in clothing. For best health conditions, a relative humidity ranging from 40% to 50% for cold weather and from 50% to 60% for warm weather, is desirable. An overall range from 30% to 70% is acceptable.

AIR CONDITIONING EQUIPMENT

Each ship generally has an organization responsible for the operation and inspection of ventilating, heating, and cooling equipment. As an Engineman, you may be a part of such an organization and should be familiar with certain elements of ship's air conditioning equipment.

VENTILATION EQUIPMENT

Since proper circulation is the basis of all ventilating and air conditioning systems and related processes, we shall first consider methods used aboard ship to circulate air. In the following sections you will find information on shipboard equipment used to supply, circulate, and distribute fresh air, and to remove used, polluted, and overheated air.

Fans used in Navy ships in conjunction with supply and exhaust systems are divided into two general classes: axial flow and centrifugal. Most fans in duct systems are of the axial flow type because they generally require less space for installation.

Centrifugal fans are generally preferred for exhaust systems that handle explosive or hot gases. The motors of these fans, being outside the air stream, cannot ignite the explosive gases. The drive motors for centrifugal fans are subject to overheating to a lesser degree than are motors of vane-axial fans.

Vane-Axial Fans

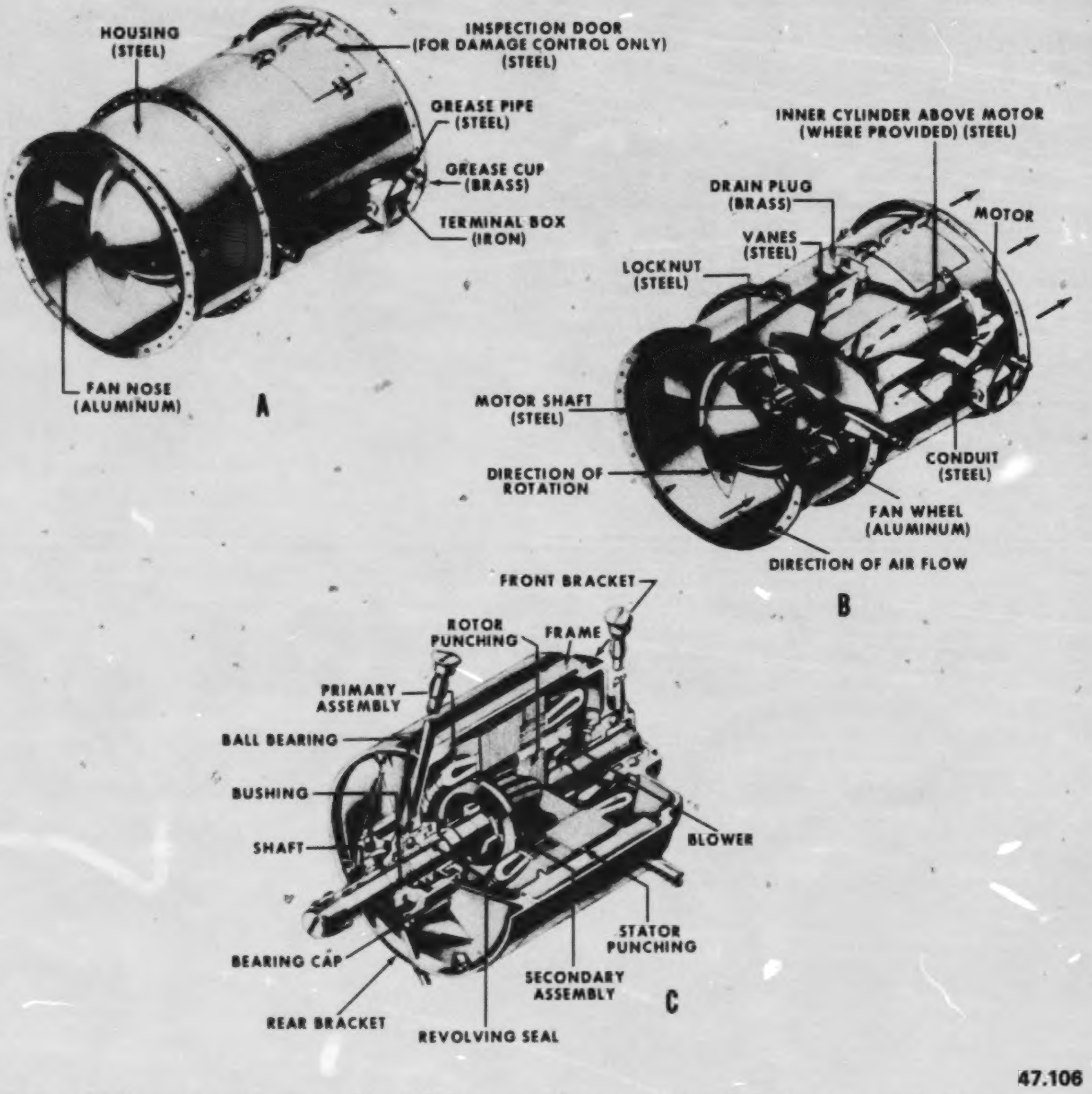
Vane-axial fans (Fig. 19-1) are high-pressure fans, generally installed in duct systems. They have vanes at the discharge end to straighten out rotational air motion caused by the impeller. The motors for these fans are cooled by the air in the duct and will overheat if operated with the air supply to the fan shut off.

Tube-Axial Fans

Tube-axial fans are low-pressure fans usually installed without duct work. However, they do have sufficient pressure for a short length of duct.

Centrifugal Fans

Centrifugal fans (part A of fig. 19-2) are used primarily for exhausting explosive or hot gases. However, they may be used in lieu of axial-flow fans if they work in better with the arrangement or if their pressure-volume characteristics suit the installation better than an axial-flow fan. Centrifugal fans are also used in some fan-coil assemblies.


HOUSING
(STEEL)
INSPECTION DOOR
(FOR DAMAGE CONTROL ONLY)
(STEEL)
GREASE PIPE
(STEEL)
GREASE CUP
(BRASS)
TERMINAL BOX
(IRON)
FAN NOSE
(ALUMINUM)
A
INNER CYLINDER ABOVE MOTOR
(WHERE PROVIDED) (STEEL)
DRAIN PLUG
(BRASS)
MOTOR
VANES
(STEEL)
LOCKNUT
(STEEL)
MOTOR SHAFT
(STEEL)
CONDUIT
(STEEL)
DIRECTION OF
ROTATION
FAN WHEEL
(ALUMINUM)
DIRECTION OF AIR FLOW
B
FRONT BRACKET
ROTOR
PUNCHING
FRAME
PRIMARY
ASSEMBLY
BALL BEARING
BUSHING
SHAFT
BLOWER
STATOR
PUNCHING
BEARING CAP
SECONDARY
ASSEMBLY
C
REAR BRACKET
REVOLVING SEAL

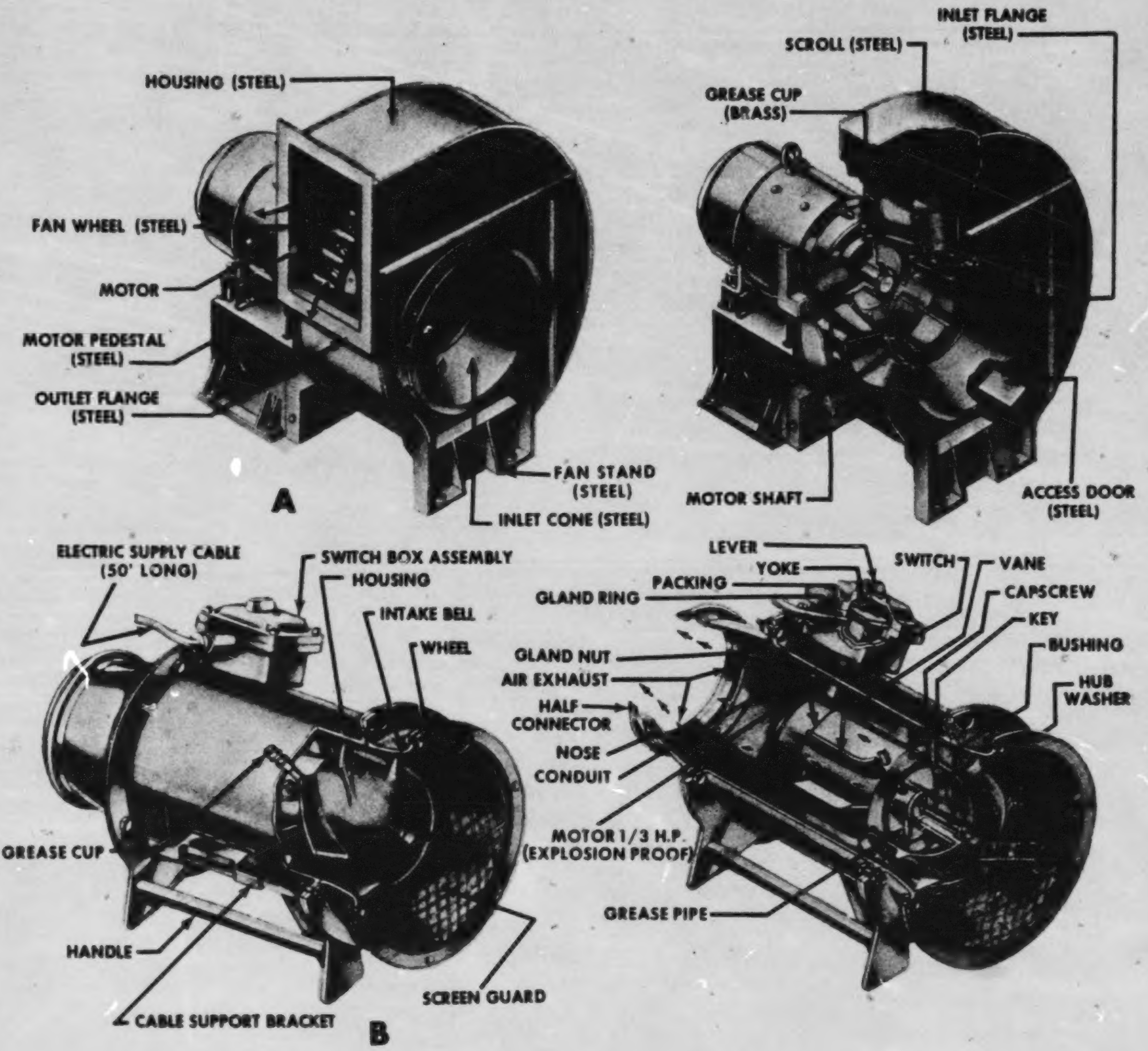
47.106

Figure 19-1.–Vane-axial ventilating fan: A. Exterior view. B. Cutaway view. C. Cutaway view of the fan motor.

Portable Fans

Portable fans (part B of fig. 19-2) with flexible airhoses are used aboard ship to ventilate compartments during and after painting, to exhaust flammable or toxic gases from closed spaces and tanks, and to cool hot spots around machinery during repairs. This type of fan is often referred to as a "Red Devil" blower.

Most portable fans are the axial-flow type, driven by electric, "explosion-proof" motors. In ships carrying gasoline, a few air turbine-driven centrifugal fans are normally provided. Greater


HOUSING (STEEL)
FAN WHEEL (STEEL)
MOTOR
MOTOR PEDESTAL (STEEL)
OUTLET FLANGE (STEEL)
FAN STAND (STEEL)
INLET CONE (STEEL)
A
SCROLL (STEEL)
INLET FLANGE (STEEL)
GREASE CUP (BRASS)
MOTOR SHAFT
ACCESS DOOR (STEEL)
ELECTRIC SUPPLY CABLE (50' LONG)
SWITCH BOX ASSEMBLY
HOUSING
INTAKE BELL
WHEEL
GREASE CUP
HANDLE
CABLE SUPPORT BRACKET
SCREEN GUARD
B
LEVER
YOKE
PACKING
GLAND RING
SWITCH
VANE
CAPSCREW
KEY
BUSHING
HUB WASHER
GLAND NUT
AIR EXHAUST
HALF CONNECTOR
NOSE
CONDUIT
MOTOR 1/3 H.P. (EXPLOSION PROOF)
GREASE PIPE

47.107

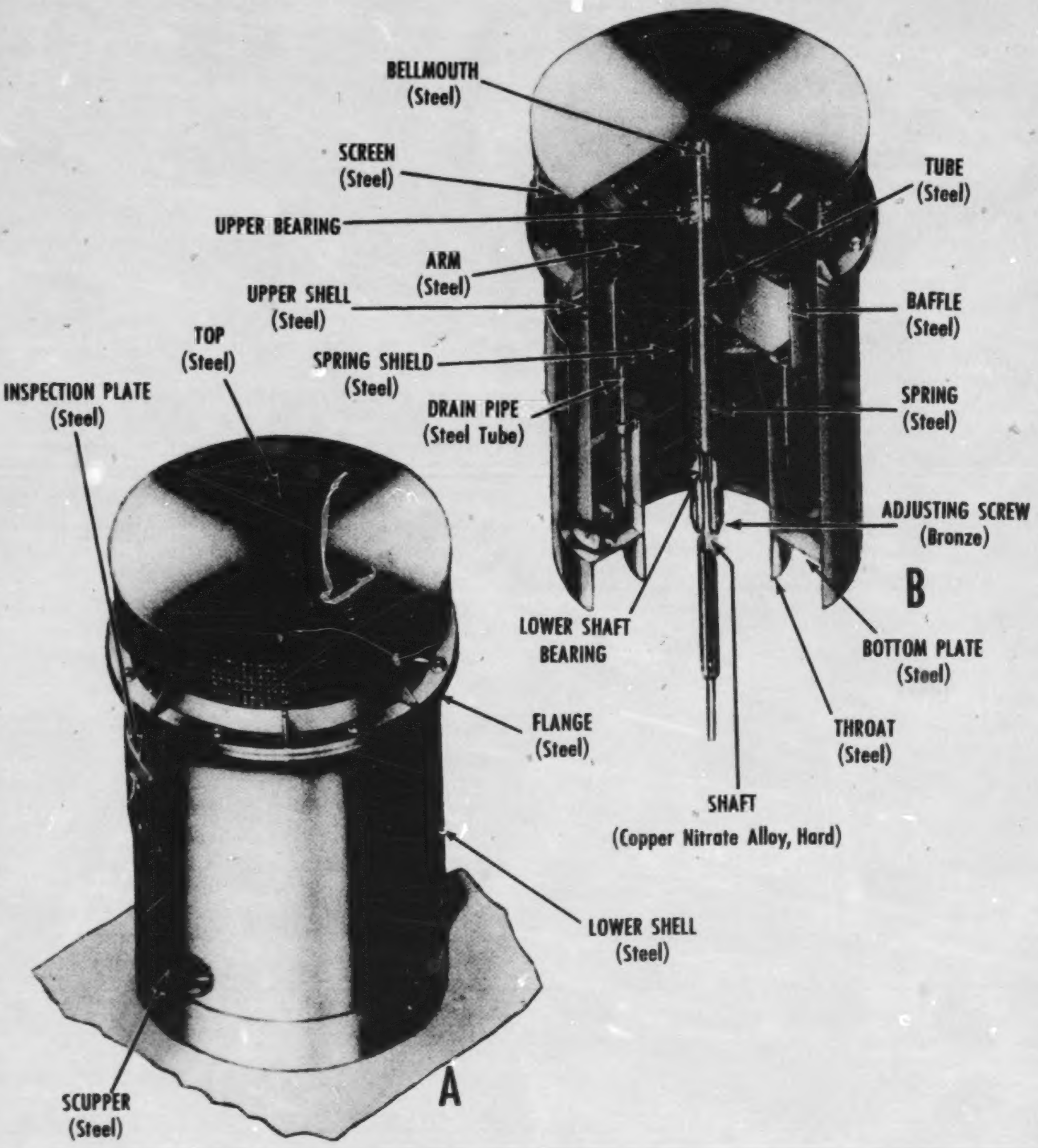
Figure 19-2.—Ventilating fans: A. Centrifugal fan. B. Portable axial fan.

confidence is placed in the explosion-proof characteristics of these fans.

Waterproof Ventilation

The waterproof ventilator, shown in figure 19-3, consists of an outer housing, an inner ventilator shaft extending up to the outer housing, and a bucket-type closure supported over the ventilator shaft by a compression spring. The bucket has drain tubes which extend into a sump between the ventilator shaft and the outer housing. The sump has scupper valves which drain onto the weather deck.

The ventilator operates automatically and is normally open. Small quantities of water, which enter the ventilator, fall into the bucket and


BELLMOUTH
(Steel)
SCREEN
(Steel)
UPPER BEARING
ARM
(Steel)
UPPER SHELL
(Steel)
TOP
(Steel)
SPRING SHIELD
(Steel)
INSPECTION PLATE
(Steel)
DRAIN PIPE
(Steel Tube)
TUBE
(Steel)
BAFFLE
(Steel)
SPRING
(Steel)
ADJUSTING SCREW
(Bronze)
B
LOWER SHAFT
BEARING
BOTTOM PLATE
(Steel)
FLANGE
(Steel)
THROAT
(Steel)
SHAFT
(Copper Nitrate Alloy, Hard)
LOWER SHELL
(Steel)
A
SCUPPER
(Steel)

47.108

Figure 19-3.—Waterproof ventilator: A. Exterior view. B. Cutaway view.

drain out through the drain tubes and scuppers. In heavy seas, when water enters the bucket faster than it drains out, the weight of water forces the bucket down against the top of the ventilator shaft. Thus, a watertight seal is formed and maintained until sufficient water drains out to permit the force of the spring to raise the bucket to the open position. Normally, some provision is made so that the ventilator can also be closed manually. With slight variations in construction, ventilation of this type may be used for both the supply and exhaust of air.

Bracket Fans

Bracket fans are used in hot weather to provide local circulation. These fans are usually installed in living, hospital, office, commissary, supply, and berthing spaces. Where air conditioning systems are used, bracket fans are sometimes used to facilitate proper circulation and direction of cold air.

Exhausts

Exhaust systems are used to remove heat and objectionable odors at their source. Machinery spaces, laundries, and galleys are but a few of the spaces aboard ship where exhausts are used.

Most exhausts used in Navy ships are mechanical although natural exhausts are sometimes provided in ship's structures and on small craft.

COOLING EQUIPMENT

On most newer ships, almost all working and living spaces are air conditioned. To determine which equipment will most effectively dehumidify and lower the temperature of compartment air, the Navy has tested several types of environmental control systems. Basically, these systems are refrigerant systems; their design and construction are dependent on the characteristics of the cooling element circulated through the system and on the principle of operation utilized.

Cooling systems can be broadly classified, according to the cooling agent circulated to the space to be cooled, as chilled-water circulating systems and refrigerant circulating systems.

Refrigerant Circulating System (Vapor Compression)

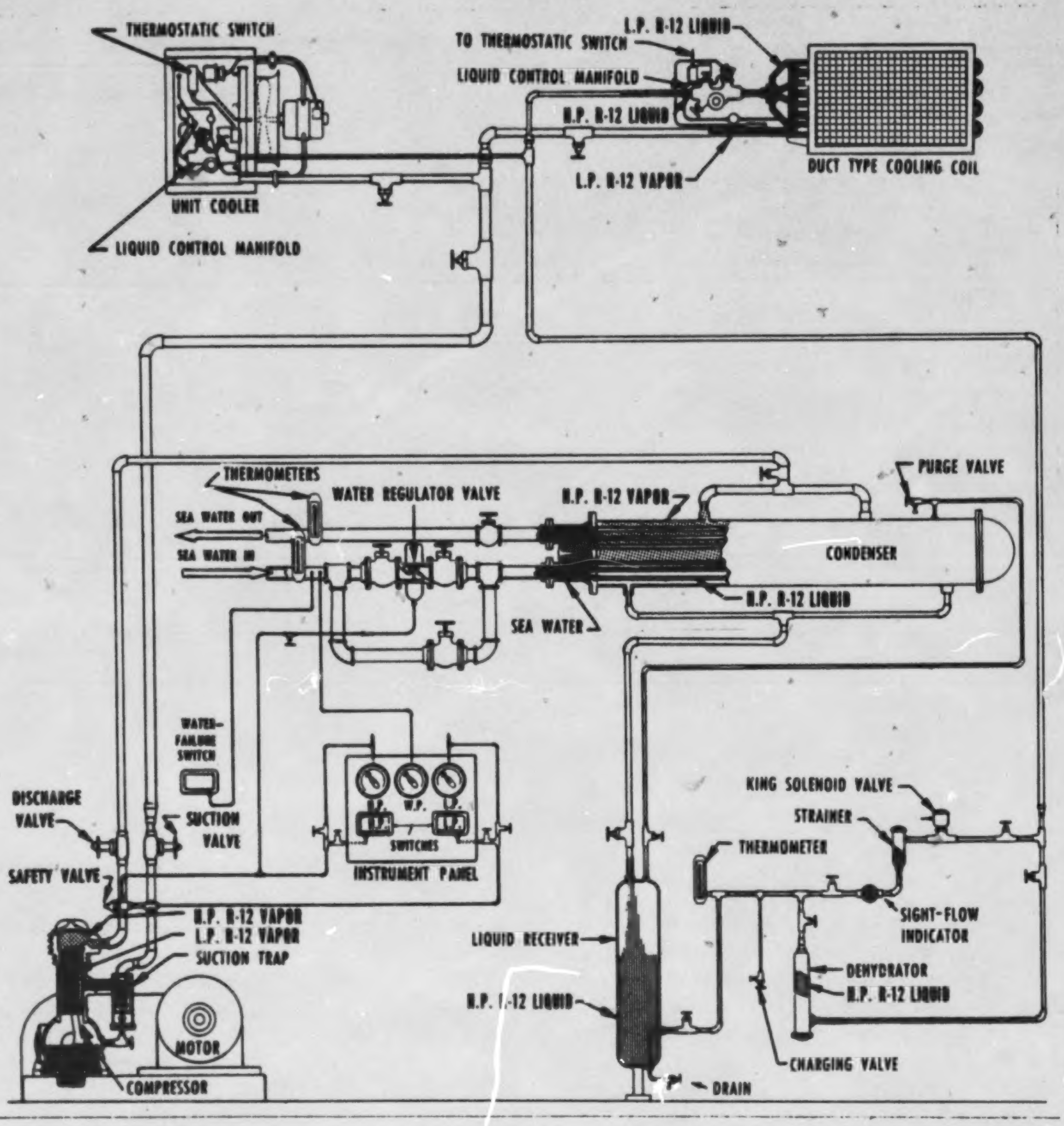
The refrigerant circulating system (fig. 19-4) is essentially a shipboard refrigerating plant, consisting of a compressor, condenser, cooling coils, fan, air filter, and the necessary controls. R-12 is the refrigerant and cooling agent used in systems of this type.

Starting at the space to be cooled, the air conditioning cycle (fig. 19-5) is as follows: The hot, moist air from the space is drawn through a duct, or passageway, where it mixes with fresh air drawn in from the outside. The fan is located to blow air over the cooling coil; the refrigerant inside the coil cools the coil surfaces. The cold surface absorbs the heat from the air passing over it causing some of the moisture in the air to condense. The condensed moisture drips off into a pan below the coil and is carried away by piping. The cooler, drier air leaving the coil is blown into the compartment that is being air conditioned, where it absorbs the excess heat and moisture in the space, and is then returned to the cooling coil by the ventilation system. Air is exhausted from the space to allow fresh air to be drawn into the space.

In general, the machinery and piping arrangements of the ship's refrigeration system and the refrigerant-circulating air conditioning system are similar.

Operating suction pressures and evaporator temperatures used in air conditioning systems are normally higher than those in refrigeration systems. The difference in suction pressure in each system results in a difference in the rated capacity of the compressor used in each of the systems.

In refrigerant-circulating air conditioning systems, the thermostatic expansion valves are usually the external equalizing type. The internal equalizing port between the valve outlet and the spring chamber is eliminated; instead there is an opening, through the valve, directly into the spring chamber. Copper tubing connects the chamber to the cooling coil, beyond the


THERMOSTATIC SWITCH
UNIT COOLER
LIQUID CONTROL MANIFOLD
L.P. R-12 LIQUID
TO THERMOSTATIC SWITCH
LIQUID CONTROL MANIFOLD
H.P. R-12 LIQUID
L.P. R-12 VAPOR
DUCT TYPE COOLING COIL
THERMOMETERS
WATER REGULATOR VALVE
H.P. R-12 VAPOR
PURGE VALVE
SEA WATER OUT
SEA WATER IN
CONDENSER
H.P. R-12 LIQUID
SEA WATER
WATER-FAILURE SWITCH
DISCHARGE VALVE
SUCTION VALVE
H.P.
W.P.
L.P.
SWITCHES
INSTRUMENT PANEL
SAFETY VALVE
H.P. R-12 VAPOR
L.P. R-12 VAPOR
SUCTION TRAP
MOTOR
COMPRESSOR
KING SOLENOID VALVE
STRAINER
THERMOMETER
SIGHT-FLOW INDICATOR
DEHYDRATOR
H.P. R-12 LIQUID
LIQUID RECEIVER
H.P. R-12 LIQUID
CHARGING VALVE
DRAIN

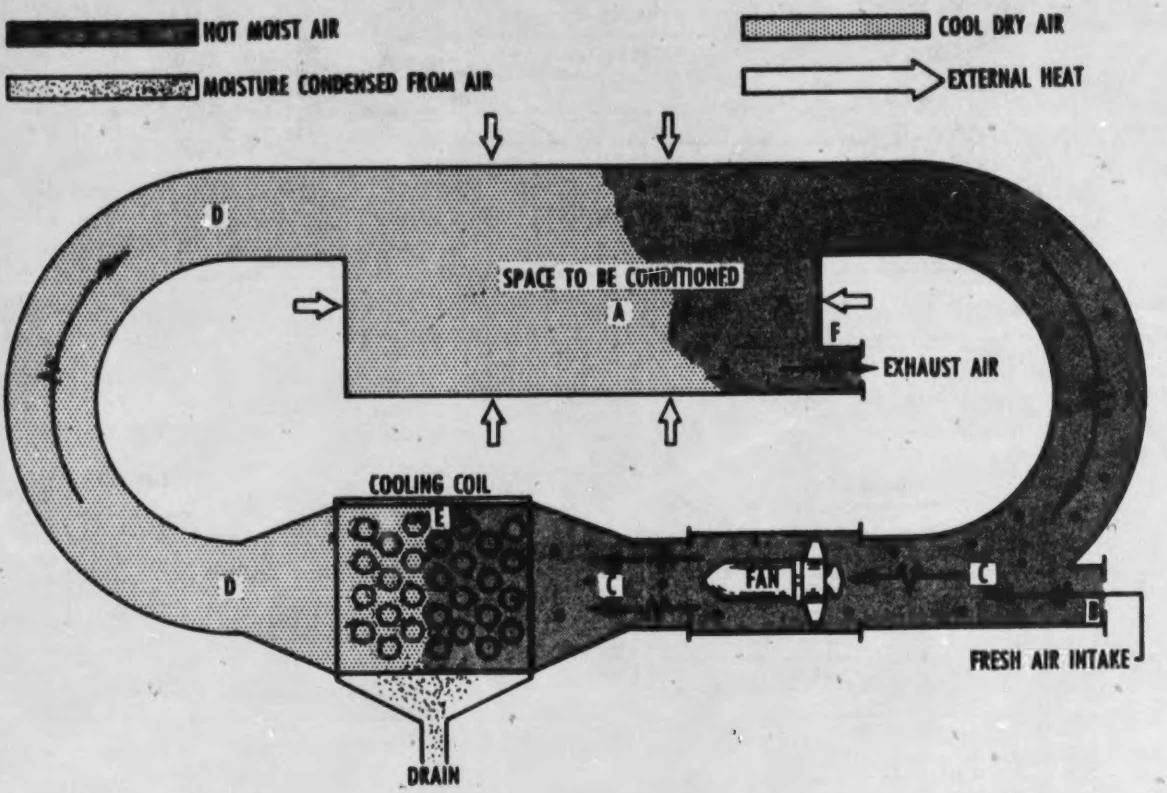
47.109

Figure 19-4.—Typical shipboard refrigerant circulating air conditioning system.

point of greatest pressure drop. In air conditioning plants, the external equalizer is needed where the pressure drop through the cooling coil is 2 1/2 psi or more or when multicircuit coils are used.

Chilled-Water Circulating Systems

There are two types of chilled-water air conditioning systems currently in use. The primary refrigerant cools the secondary



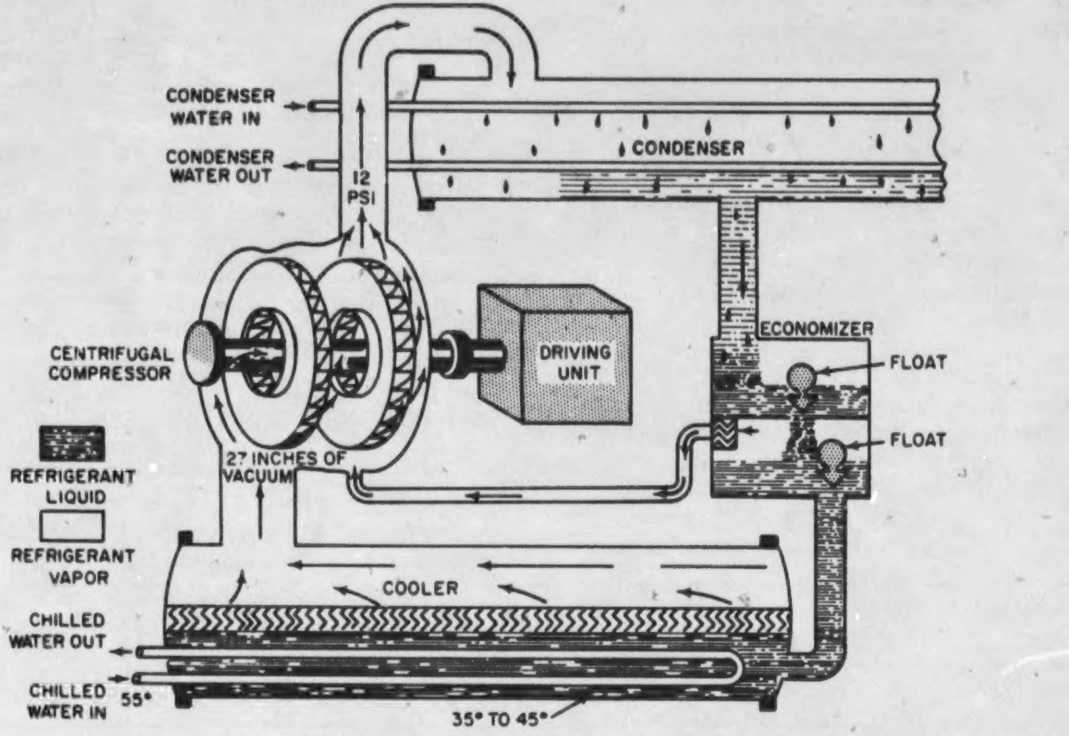
75.253

Figure 19-5.—Mechanical air-cooling cycle.

refrigerant (chilled water) which is used to cool the spaces. One type of system operates on the vapor compression cycle with R-11 or R-12 used as the primary refrigerant; the type of primary refrigerant used will depend on the size of the unit and the type of compressor installed. The other type of system operates on the absorption cycle and uses water as both primary and secondary refrigerants; lithium bromide is used as an absorbent. We will discuss only the vapor compression cycle.

VAPOR COMPRESSION.—The vapor compression chilled-water circulating system differs from a direct expansion air conditioning system in that the air conditioning is accomplished by a secondary refrigerant (chilled water) which is circulated to the various cooling coils. Heat from the air conditioned space is absorbed by the circulating chilled water and is removed from the water by the primary refrigerant system in the water chiller. In larger capacity air conditioning systems, the compressor may be a centrifugal type that uses R-11 as the primary refrigerant rather than a reciprocating type that uses R-12.

The operating cycle of the centrifugal air conditioning unit (fig. 19-6) is basically the same as most refrigerating machines except for the method of compression. The refrigerant vapor coming from the cooler goes into an opening around the hub of an impeller wheel. The blades in the rapidly rotating wheel impart velocity and compress the vapor. In a multistage compressor, the vapor is next directed to the hub of an additional wheel or wheels. The vapor is


CONDENSER WATER IN
CONDENSER WATER OUT
12 PSI
CONDENSER
ECONOMIZER
FLOAT
FLOAT
CENTRIFUGAL COMPRESSOR
DRIVING UNIT
REFRIGERANT LIQUID
REFRIGERANT VAPOR
27 INCHES OF VACUUM
COOLER
CHILLED WATER OUT
CHILLED WATER IN
55°
35° TO 45°

75.110

Figure 19-6.—Chilled water circulating system, with a centrifugal compressor.

compressed to about 12 psi and discharged to the condenser.

Between the condenser and the cooler on multistage units, the liquid refrigerant passes through an economizer. A float in the upper chamber of the economizer allows the refrigerant to pass into the lower chamber. By connecting the economizer to the second stage of the compressor, the pressure in the lower chamber is greatly reduced. This reduction of pressure causes some of the liquid refrigerant to flash into vapor and cool the remainder of the refrigerant. Thus, the economizer acts as an interstage flash cooler and increases the efficiency of the plant. A float in the lower chamber of the economizer allows the refrigerant to pass into the cooler. In the cooler, the liquid refrigerant changes its state into vapor and in so doing absorbs heat from the water.

Water is pumped through the cooler (fig. 19-6) where it loses heat to the refrigerant. The water leaves the cooler at 45° to 50°F (7.2° to 10°C) and is directed to the compartment to be cooled.

The centrifugal compressor (fig. 19-6) is the two-stage type and consists of the casing, rotor, bearings, shaft, impellers, and shaft seal. Centrifugal compressors are usually motor driven through a speed increasing gear which ensures proper compressor speed with a standard speed motor. The speed increasing gear is the double-helical type, pressure lubricated by a gear-type oil pump which is driven from the compressor shaft.

Some centrifugal compressors are turbine driven and do not need a speed increasing gear. The majority of centrifugal air conditioning compressors recently installed in Navy ships are single stage. The multistage economizer functions described are not applicable to centrifugal air conditioning units that have single-stage compressors.

The chilled-water cooler is the shell and tube type. A gas baffle above the tubes prevents the carryover of liquid refrigerant to the compressor suction. When the plant is shut down, the normal refrigerant charge covers about 50% of the tubes; however, when the plant is in operation, the boiling refrigerant covers all of the tubes.

The following controls and safety devices are typical of those installed on a centrifugal refrigerating system. (Control settings are approximate since they will vary with differences in design.)

1. The CONDENSER GAGE indicates the pressure corresponding to the condensing temperature.

2. The COOLER GAGE indicates the pressure corresponding to the condensing temperature.

3. The OIL GAGE indicates the lube oil pressure within the lubricating system.

4. The HIGH-PRESSURE SWITCH is actuated by the condenser pressure and is set to cut in at 5 psig and to cut out at 15 psig.

5. The COMPRESSOR LOW LUBE OIL PRESSURE SWITCH is actuated by the compressor oil pressure and is set to cut in at 12 psig and to cut out at 6 psig.

6. The GEAR LOW LUBE OIL PRESSURE SWITCH is actuated by the gear oil pressure and is set to cut in at 15 psig and to cut out at 6 psig.

7. The CONDENSER WATER PRESSURE FAILURE SWITCH is actuated by the seawater pressure and is set to cut in at 15 psig and to cut out at 5 psig.

8. The CHILLED-WATER DIFFERENTIAL PRESSURE FAILURE SWITCH is actuated by the chilled water pressure and is set to cut in at 20 psig and to cut out at 16 psig.

9. The REFRIGERANT TEMPERATURE CONTROL SWITCH has its thermal bulb located in the cooler. It is set to cut out at 30°F (-1.1°C) and to cut in at 40°F (4.4°C).

10. The CHILLED-WATER TEMPERATURE CONTROL SWITCH has its thermal bulb located in one of the tubes in the chilled-water cooler. It is set to cut out at 42°F (5.5°C) and to cut in at 50°F (10°C).

11. The OIL HEATER START AND STOP BUTTON controls the electric heater located in the oil pump chamber of the compressor. The oil heater limits the amount of refrigerant absorption during shutdown. The heater should be turned on when the compressor is not running and turned off when the plant is operating.

The contacts of all safety devices are closed under normal conditions. Opening the contacts of any safety device stops the compressor. After the cause of the abnormal condition has been determined and corrected, the compressor must be started in the usual way.

The centrifugal refrigerating unit operates on the usual compression cycle. The cycle, starting at the cooler, is as follows:

The water flowing through the cooler tubes is warmer than the refrigerant on the outside of the tubes. The heat transfers from the water to the refrigerant. The heat evaporates the refrigerant. The evaporated refrigerant (vapor) is drawn into the compressor by the first-stage impeller. The first-stage impeller compresses the vapor and discharges it to the second-stage impeller. Here it joins a stream of vapor coming from the economizer. Compression of the two streams is completed by the second stage and the compressed vapor is discharged to the condenser.

In the condenser, the vapor condenses to a liquid and drains into the condenser float chamber. The rising refrigerant level opens the float valve and allows the liquid refrigerant to pass into the economizer chamber which has a connection to the second stage of the compressor. Enough of the liquid evaporates to cool the remainder to the temperature corresponding to the pressure in the economizer. As the liquid collects in the economizer float chamber, the rising level opens the float valve and allows the liquid to pass to the cooler.

Packaged Unit Air Conditioners

Packaged unit air conditioners are now being installed in some ships that were built without air conditioning. This type of air conditioner has the entire unit in one metal cabinet. Installation is simple; only the mounting brackets, electrical leads, drain lines, and the cooling water lines are necessary for complete installation.

Compressing elements in packaged unit air conditioners are usually the hermetic type (motor and compressor are contained in a welded steel shell). Repairing the compressor or motor aboard ship is impractical; the assembly should be replaced as a unit.

Compressor discharge pressures vary from 120 psig to 200 psig; suction pressures vary from 30 psig to 65 psig. The temperature DROP of the air across the cooling coil is usually about 16° to 18°F or -8.9° to -7.8°C.

Some packaged unit air conditioners have a thermal expansion valve similar to the type used on the ship's refrigeration plant; many types have one or more capillary tubes.

A capillary tube is a small copper tube with about 1/16-inch inside diameter. The tube acts as a restriction (or orifice) to reduce the pressure of the liquid refrigerant, just prior to its entering the cooling coil. The effect on the refrigerant is the same as when it passes through an expansion valve. Some air conditioners have as many as 11 capillary tubes to ensure an even flow of refrigerant throughout the cooling coil.

The high-pressure and low-pressure switches are set and sealed at the factory. The only adjustable controls are the water regulating valve and the thermostat. The principle of operation and the adjustment of the water regulating valve are the same as for the one used on the ship's refrigerating plant.

To set the thermostat, you may use the following procedures:

1. In the air conditioned compartment, place a thermometer at a point where the desired room temperature is of most importance.
2. Turn the thermostat control to the coldest position.
3. When the desired temperature is reached, slowly turn the thermostat control toward the "warmer" position until the compressor stops.

Fan-Coil Assemblies

Fan-coil assemblies are prefabricated air conditioners, consisting of a fan and motor, air filters, coil bypass damper, thermal and acoustical insulation, and a chilled-water coil enclosed in a metal cabinet, used in conjunction with a chilled-water system for air conditioning spaces in all types of ships.

The fan-coil assembly may be used in lieu of a fan room aboard ship. The assembly may be installed with or without ductwork. The assembly has outlets on the top, front, and ends of the cabinet. The outlet may be used singly or in multiples of zone air distribution with ductwork or for free air delivery without ductwork. A cooling coil bypass is also provided. When the air conditioner is installed outside the space being served, the installing activity provides the ductwork between the air conditioned space and the cooling coil bypass inlet. This is to ensure that return air is used for bypass and not replenishment air.

The fan in the assembly is a belt-driven centrifugal fan. The belt drive permits a varying capacity to fit the application, depending on the use or extent of ductwork.

The cooling coil has copper tubes, fins, and headers. The coil is eight rows deep in direction of airflow and has a vent and drain cocks. The vent and drain are accessible through a removable access panel.

The assembly has a fixed bypass manual locking type damper mounted as an integral part of a removable end panel. All working mechanisms of the damper are enclosed inside the cabinet to prevent adjustment of the damper from the exterior of the cabinet without removing the panel.

Access for removal of the fan, fan drive, motor, and cooling coil is through removable end panels. The removable end panels are interchangeable on each assembly. A front access opening permits servicing, adjustment and removal of the motor, fan bearings, pulleys, and belts from the front of the cabinet.

The removable panels and access openings are gasketed and airtight under normal operating conditions.

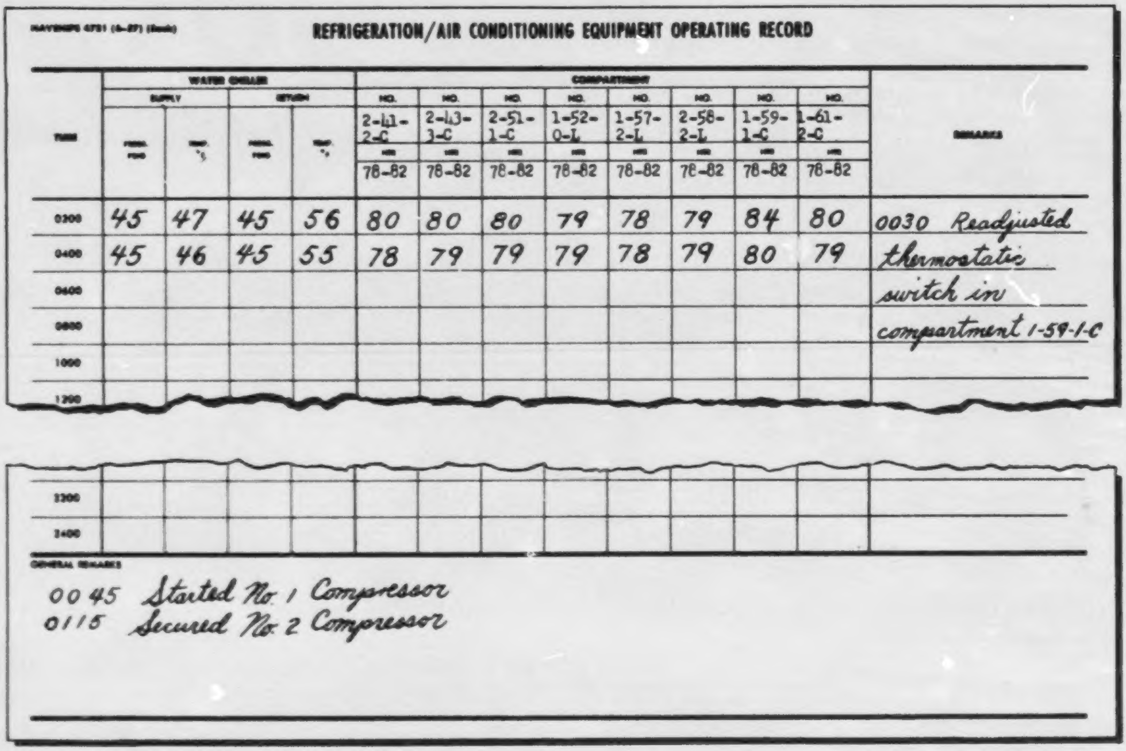
Access openings on each end of the cabinet permit servicing to the air filters.

Gravity Cooling Coils

In places such as ammunition magazines, it is impractical to have ventilation ducts or a package unit installed. Since cooling of the space is necessary, the gravity cooling coil is used. The coil is usually installed in the upper part of the space and is supplied by chilled water from the main system. Since it is a gravity type coil, heat removal is dependent upon convection currents across the coil. The switch mechanism for the thermostatic valve is located outside the space for safety reasons.

Air Conditioning Equipment Operating Record

A daily operating record (NAVSHIPS 4731) is maintained for all air conditioning equipment except packaged unit air conditioners. Figure 19-7 shows the back of the form on which compartment temperatures and chilled-water pressures and temperatures are recorded. The main difference in filling in the front of NAVSHIPS 4731 is that compressor suction and discharge temperatures and pressures will be



[illegible]

REFRIGERATION/AIR CONDITIONING EQUIPMENT OPERATING RECORD

TIME	WATER CHILLER				COMPARTMENT								REMARKS
	SUPPLY		RETURN		NO. 2-41-2-C	NO. 2-43-3-C	NO. 2-51-1-C	NO. 1-52-0-L	NO. 1-57-2-L	NO. 2-58-2-L	NO. 1-59-1-C	NO. 1-61-2-C	
	[illegible]	[illegible]	[illegible]	[illegible]	78-82	78-82	78-82	78-82	78-82	78-82	78-82	78-82	
0200	45	47	45	56	80	80	80	79	78	79	84	80	0030 Readjusted
0400	45	46	45	55	78	79	79	79	78	79	80	79	thermostatic
0600													switch in
0800													compartment 1-59-1-C
1000													
1200													
2200													
2400													

GENERAL REMARKS

0045 Started No. 1 Compressor
0115 Secured No. 2 Compressor

47.104.2

Figure 19-7.—Air conditioning equipment operating record (back) NAVSHIPS 4731.

higher for air conditioning plants than for refrigeration plants.

Air Filters

Navy standard air filters have pressure taps on each side of the filter bank. By using a portable differential pressure gage, you can quickly read the pressure drop across the filter. When the pressure drop increases to three times that of a clean filter, the filter must be cleaned. Ships may be provided with spare filters so that a clean one may be substituted for the dirty one. A systematic procedure should be set up for cleaning all filters in the ship.

Special cleaning sinks are installed in ships that have a sufficient number of filters to justify the space, expense, and weight. These sinks may be of the steam type where steam is used to heat and agitate the water or of the ultrasonic type where cleaning is done by vibration due to sound waves passing through the cleaning fluid.

Navy standard air filters have a thin film of oil applied to the wires. The oil film retains fine particles of dust and lint. After washing, the filters should be re-oiled by spraying with filter oil. Sprayers furnished for oiling air filters must NOT be used for any other purpose to avoid the possibility of contaminating the filters with toxic, flammable, or smelly materials.

FLAME ARRESTERS AND GREASE FILTERS SHOULD NEVER BE OILED.

MAINTENANCE OF COOLING EQUIPMENT

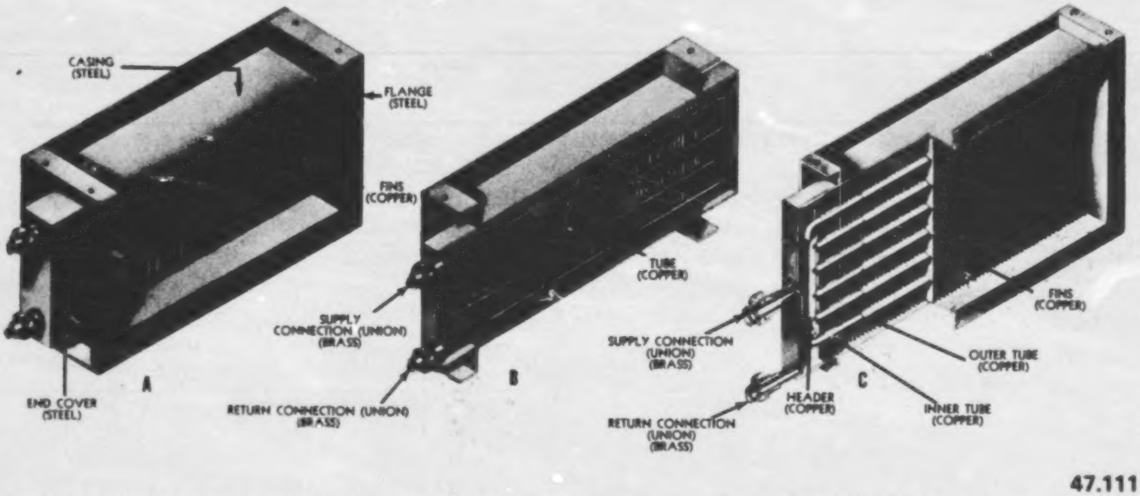
Since air conditioning systems are similar in many ways to refrigeration plants, much of the information in this manual concerning refrigeration is equally applicable to air conditioning equipment.

To ensure proper maintenance of any air conditioning plant, the requirements of the 3-M System must be strictly adhered to.

HEATING EQUIPMENT

DUCT HEATERS

Duct heaters (fig. 19-8) are installed in duct systems and are used wherever feasible because of savings in weight, space, and piping. These heaters are built to withstand considerable shock and have standard connections to simplify piping. The steam flows through copper tubes which are arranged in a single row.


CASING (STEEL)
FLANGE (STEEL)
FINS (COPPER)
END COVER (STEEL)
A
TUBE (COPPER)
SUPPLY CONNECTION (UNION) (BRASS)
RETURN CONNECTION (UNION) (BRASS)
B
FINS (COPPER)
SUPPLY CONNECTION (UNION) (BRASS)
OUTER TUBE (COPPER)
C
HEADER (COPPER)
INNER TUBE (COPPER)
RETURN CONNECTION (UNION) (BRASS)

47.111

Figure 19-8.–Ventilation heaters: A. Exterior view of S-type heater. B. Tube arrangement of S-type heater. C. Tube arrangement of T-type heater.

Two different types of coil arrangements are used. Part B of figure 19-8 shows the "S" arrangement with the tubing serpentined. The S-type is used in small size heaters. For large size heaters the S-type is not efficient.

Part C of figure 19-8 shows a "T" arrangement which has a copper tube within a tube (a 3/8-inch distributing tube inside a 5/8-inch outer tube). Steam pressures up to 150 psi may be used in these heaters.

Large ventilation supply systems, except those serving machinery spaces, have a PREHEATER at or near the weather intake. By locating the heater near the intake, the duct temperature is kept high enough to avoid condensation during cold weather operation.

In the majority of the systems that use a preheater, there is also a REHEATER(s). In circulating cooling systems, reheaters maintain specified space temperatures during cold water operation.

Reheaters supply either single spaces or zones. Zones are made up of spaces that are expected to have similar heat loads. Reheaters are controlled by room thermostats. In recirculating cooling systems in newer ships, the reheaters use a constant supply of steam to reheat air to any zone which would be overcooled.

In small ventilation systems with short duct runs where one heater will produce the required temperature rise, a COMBINATION HEATER is used alone. This heater has two separate heating coils in one housing. Each coil has its own steam supply and is controlled by an individual thermostat. Combination heaters may also be used with reheaters to supply more than one space where the combination heater is sufficient to maintain the required temperature rise in one of the spaces.

CONVECTOR HEATERS

Convector heaters (fig. 19-9) are installed in small spaces or in spaces that are not fitted with mechanical supply ventilation. These heaters have a high heating capacity for their size and weight, are considerably smaller than radiators or pipe-coils of the same capacity, and will withstand severe shock. A steam pressure up to 150 psi can be used in the heaters, or a forced hot water system can be used. When they are used with steam pressure between 25 and 50 psi, temperature differentials at different levels in the room are reduced. Heating is regulated by the air bypass damper in the front part of the heater. The cabinets are generally of steel, though they may be (if desired) of nonmagnetic stainless steel, copper, or aluminum.

UNIT HEATERS

Unit heaters (fig. 19-10) are self-contained heating units comprised of a fan, fan motor, heating coil, and adjustable louvers. They are used in special cases such as when the amount of supply ventilation is too small to provide sufficient heat through ventilation heaters, or where there is no mechanical ventilation supply and the heat requirements exceed the capacity of convector heaters. They can be used with either steam pressure up to 150 psi or with forced hot water systems. Composite parts of the heaters include the heat transfer surface (fins and tubes), fan, thermostatic control valve, strainer, trap, and directional louvers.

ELECTRIC HEATERS

Electric heaters are used in spaces located at a considerable distance from the steam piping system or in spaces where the use of steam duct heaters would be impractical. They are built in many types and designs; because of electrical hazards only those heaters approved by the Navy should be used.

HEATING CONTROLS

Temperature regulators that control the flow of steam to ventilation heaters and unit heaters consist of a thermostatic assembly (bulb, tubing,

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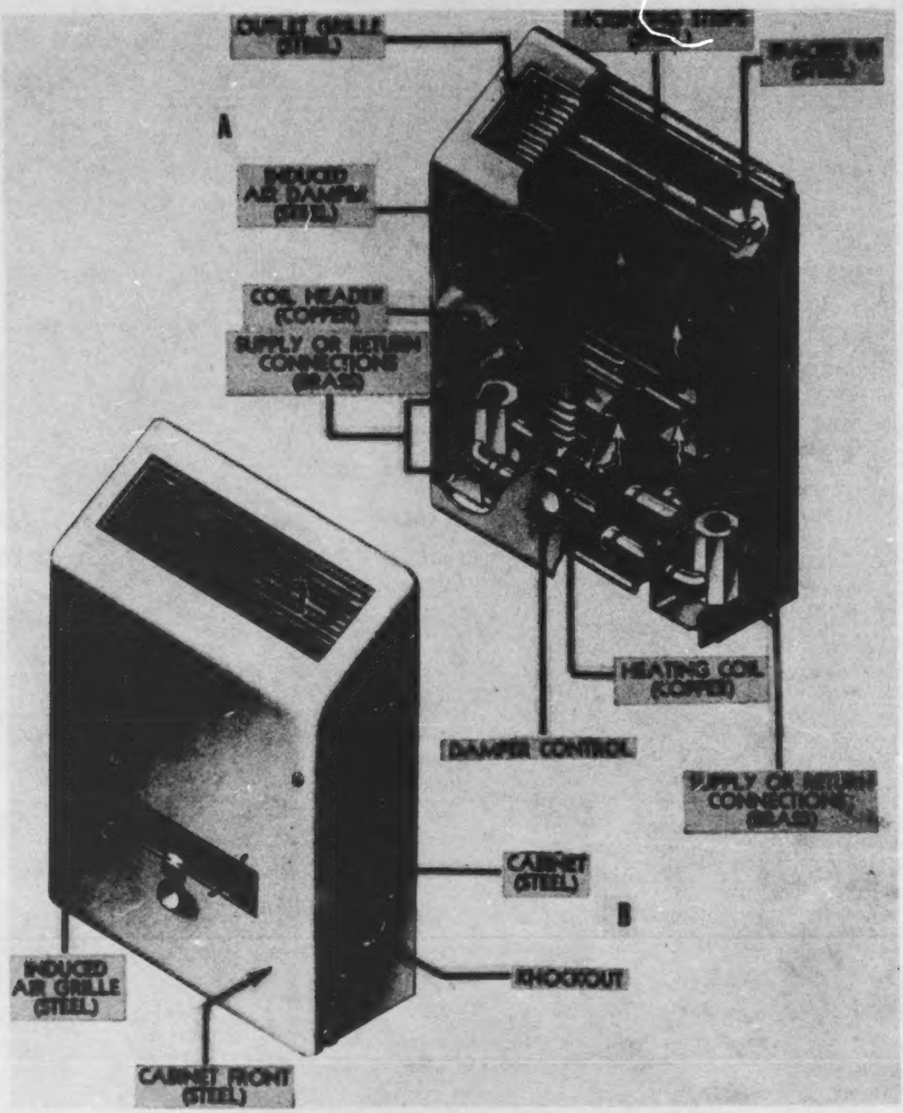
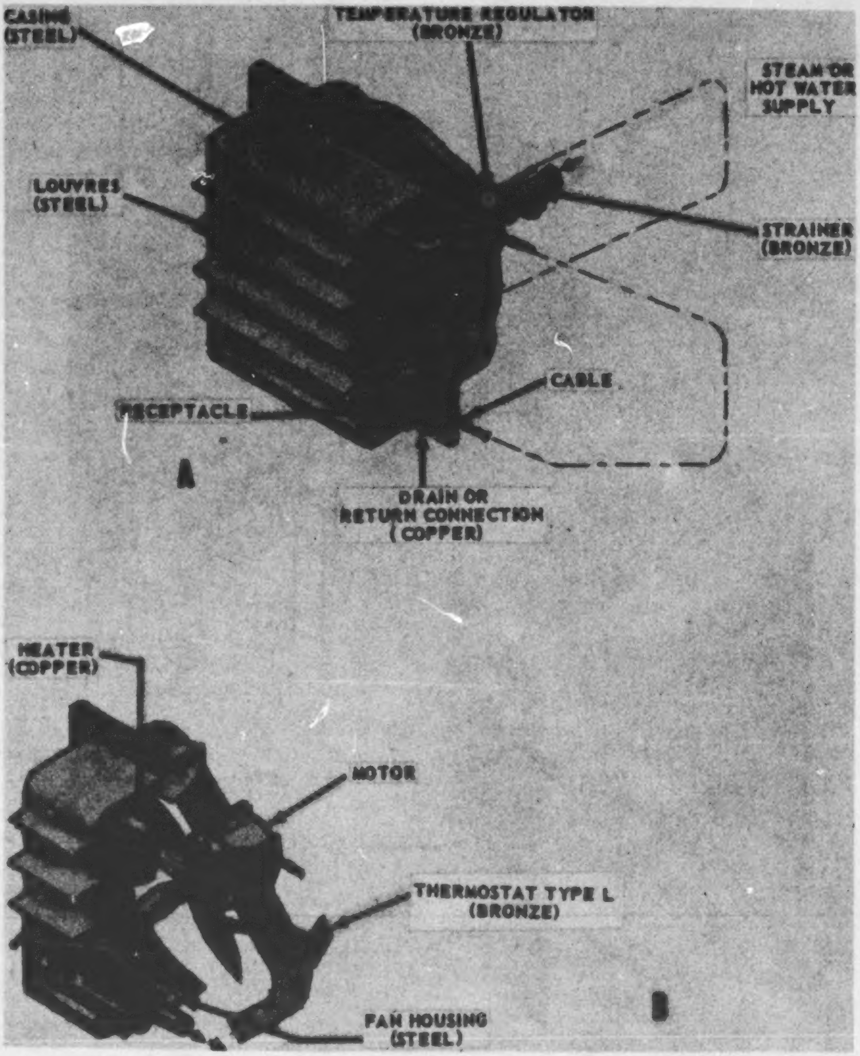

OUTLET GRILLE (STEEL)
A
INDUCED AIR DAMPER (STEEL)
COIL HEADER (COPPER)
SUPPLY OR RETURN CONNECTIONS (BRASS)
HEATING COIL (COPPER)
DAMPER CONTROL
SUPPLY OR RETURN CONNECTIONS (BRASS)
CABINET (STEEL)
B
KNOCKOUT
INDUCED AIR GRILLE (STEEL)
CABINET FRONT (STEEL)

47.112

Figure 19-9.—Convector heater: A. Cutaway view. B. Exterior view.

and motor bellows) and a valve assembly. (See figures 19-11 and 19-12.) The thermostatic assembly contains just enough volatile liquid to fill the bulb and tubing but not the motor bellows in the valve. A rise in temperature on the bulb causes liquid to flow through the tubing and into the motor bellows located in the hot chamber assembly of the valve. As the liquid enters the motor bellows, it is vaporized by the temperature of the steam surrounding the bellows. The pressure (thus developed in the bellows) overcomes the spring load which normally holds the valve open. This causes a gradual closing of the valve. A decrease in


CASING
(STEEL)
TEMPERATURE REGULATOR
(BRONZE)
STEAM OR
HOT WATER
SUPPLY
LOUVRES
(STEEL)
STRAINER
(BRONZE)
CABLE
RECEPTACLE
A
DRAIN OR
RETURN CONNECTION
(COPPER)
HEATER
(COPPER)
MOTOR
THERMOSTAT TYPE L
(BRONZE)
B
FAN HOUSING
(STEEL)

47.113

Figure 19-10.—Unit heater: A. Exterior view. B. Cutaway view.

temperature on the bulb reverses the process, allowing vapor to leave the bellows, to condense in the tubing, and to permit the spring load to open the valve. In this manner the valve will open and close gradually to pass just the right amount of steam necessary to react to the changes in temperature around the thermostatic bulb.

Thermostat

The thermostatic bulb, tubing, and motor bellows are integral with the thermostat and cannot be separated. When any part of the assembly is damaged, the entire assembly must be replaced. The tubing connects the bulb to the motor bellows and is armored for protection. The types of thermostats designed for use with ventilation and unit heater regulators are the R, L, and W thermostats.

The type R thermostat (part A of fig. 19-11) is designed for mounting on a bulkhead or on a stanchion within the space served by a combination heater, a reheater, or a unit heater. The temperature regulator of a type R thermostat is adjusted by rotating the adjusting knob which extends or contracts the adjusting bellows. Clockwise rotation of the knob extends the adjusting bellows which decreases the liquid capacity of the bulb thereby forcing liquid into the motor bellows and closing the valve. The valve will not reopen until a lower temperature at the thermostat acts on the bulb to provide space for the previously ejected liquid. Reverse rotation of the adjusting knob raises the temperature setting by increasing the liquid capacity of the bulb. The type R thermostat is used with valves governing the flow of steam to combination heaters, reheaters, and unit heaters.

The type L thermostat (part B of fig. 19-11) is a duct-mounted, adjustable thermostat used with valves governing the flow of steam to preheaters. This thermostat is flange-mounted in the duct, 4 to 6 feet after the preheater. The main control element of the bulb extends into the air stream inside the duct. The type L thermostat operates in the same manner as the type R thermostat.

The type W thermostat (part C of fig. 19-11) is nonadjustable, preset at the factory to be fully open when the air temperature at the thermostat drops to 35°F. The thermostat may be located in the air stream ahead of the preheater or in any other location where its operation will be governed by the weather. When the thermostat is located on the weather decks, it must be shielded from the effects of the sun (or other heat sources) by a bulkhead or deck. The type W thermostat is used with the Model D valve (part B of fig. 19-12) and functions to prevent freezing of the condensate in the preheater tubes by allowing the valve to admit steam to the preheater when the temperature of the incoming air drops below 35°F. or 1.7°C.

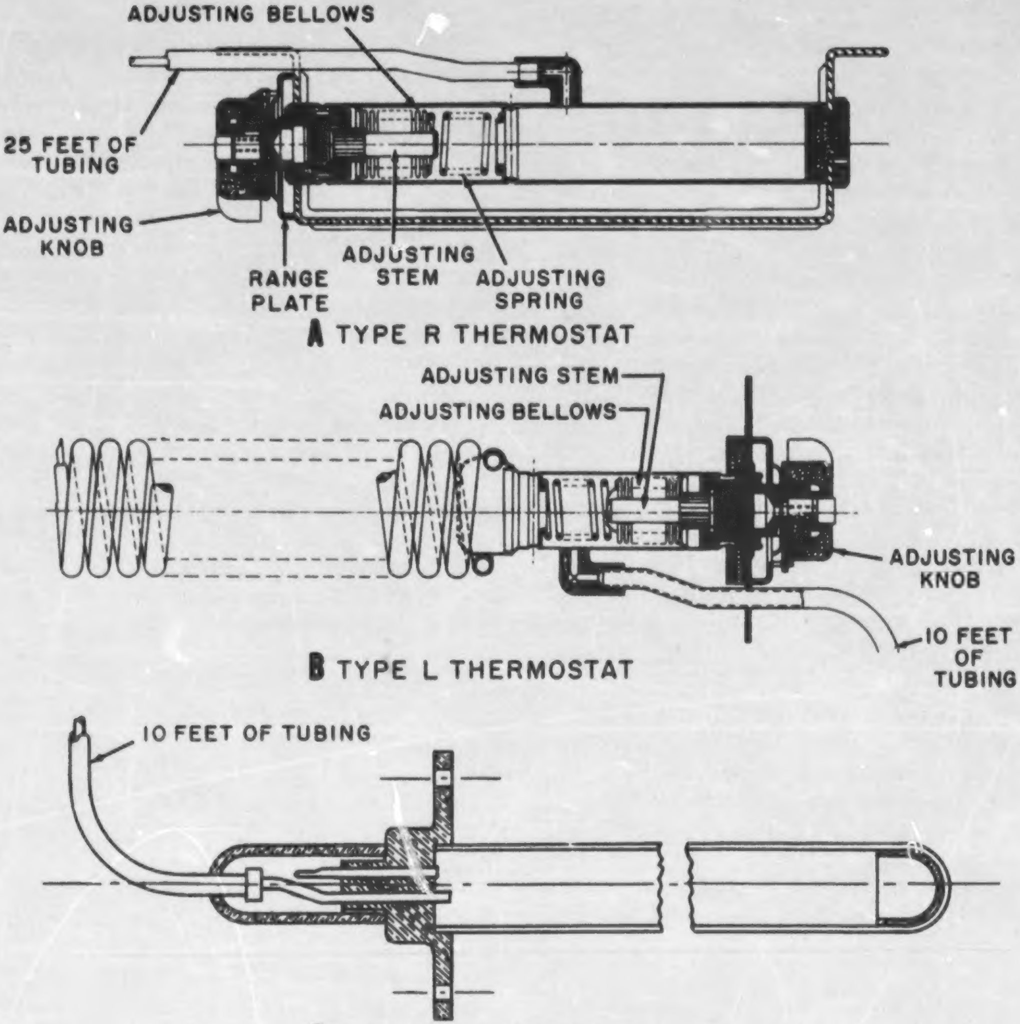
Valves

Three types of valves designed for use with ventilation and unit heater regulators are the Model E, Model G, and Model D valves. Use of the Model E, G, and D valves is determined by the designated capacity of the heaters. The Model E valve (part A of fig. 19-12) is available in sizes to govern steam flow in the range of 5 to 350 pounds of steam per hour. The Model E valve has a needle type poppet and seat and can be used with a type W, L, or R thermostat to regulate steam flow to a ventilation or unit heater.

The Model G valve is similar to the Model E valve except that it has an additional bellows (balancing bellows) located under the valve poppet and connected to the valve stem. This valve is available in various sizes to handle steam capacities in the range of 450 to 900 pounds of steam per hour. It is designed to be used with a type R or L thermostat to regulate steam flow in a ventilation heater.

The Model D valve (part C of fig. 19-12) is actually two Model E valves in a common valve body; it is intended for use only on preheaters or combination heaters. One of the valves is sized to pass about 75% of the load rating of the Model D valve; it is actuated by a type L thermostat (when used with a preheater) or a type R thermostat (when used to regulate steam flow in a combination heater). The other valve is sized to pass about 25% of the load rating of the Model D valve; it is actuated by a type W thermostat, when the temperature of the incoming air drops below 35°F, or 1.7°C, to ensure sufficient steam in the preheater or combination heater to prevent freezing of the condensate in the heater tubes.

The capacity of the Model D valve is the combined capacity of two E-type valves. For example, a Model D valve intended for use with a heater capacity of 40 pounds of steam per hour would use two E-type valves with the one for the W thermostat side rated at 10 pounds of steam per hour and the one for the L or R thermostat side rated at 30 pounds of steam per hour.

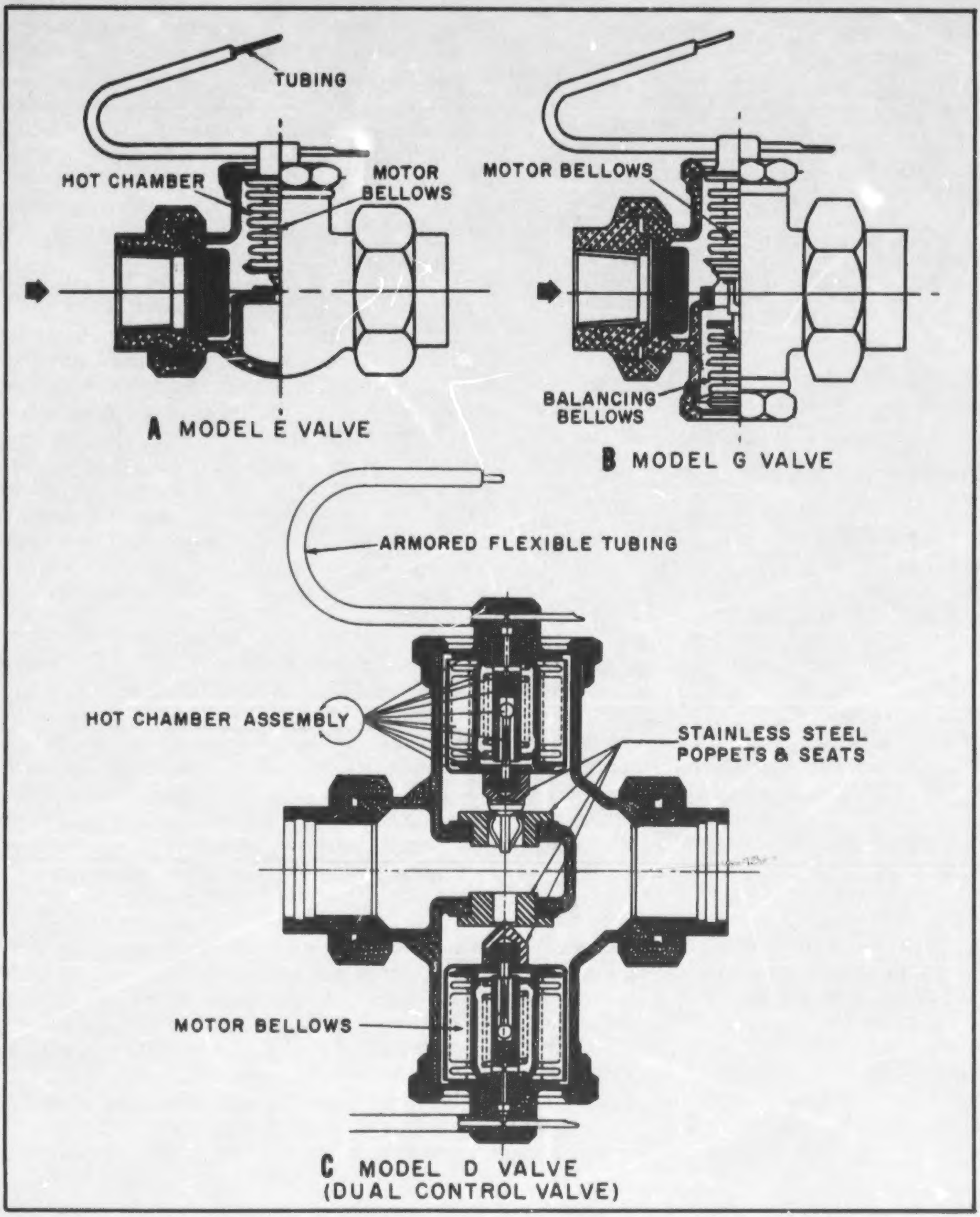

ADJUSTING BELLOWS
25 FEET OF TUBING
ADJUSTING KNOB
RANGE PLATE
ADJUSTING STEM
ADJUSTING SPRING
A TYPE R THERMOSTAT
ADJUSTING STEM
ADJUSTING BELLOWS
ADJUSTING KNOB
10 FEET OF TUBING
B TYPE L THERMOSTAT
10 FEET OF TUBING
C TYPE W THERMOSTAT

75.292

Figure 19-11.—Types of thermostats.

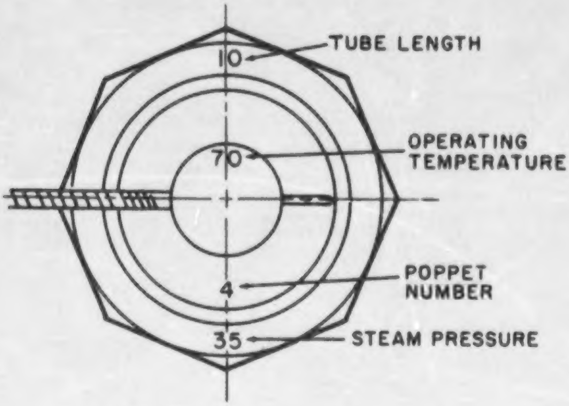
The temperature regulator is adjusted by rotating the adjusting knob on the type L or R thermostat to the desired temperature shown on the range plate which is calibrated in degrees Fahrenheit. After 5 minutes of operation of the heater at the desired setting, check the temperature of the air in the space with a calibrated thermometer. If further adjustment is necessary, move the setting only 1° or 2°F (.5° to 1°C) and allow another period of 5 minutes to elapse before rechecking with the thermometer.

Information concerning the valve and thermostatic assemblies is found on the valve bonnet which is stenciled as shown in figure 19-13, with numerals indicating the tube length, operating temperature of the motor bellows, poppet number, and steam pressure.


TUBING
HOT CHAMBER
MOTOR BELLOWS
A MODEL E VALVE
MOTOR BELLOWS
BALANCING BELLOWS
B MODEL G VALVE
ARMORED FLEXIBLE TUBING
HOT CHAMBER ASSEMBLY
STAINLESS STEEL POPPETS & SEATS
MOTOR BELLOWS
C MODEL D VALVE
(DUAL CONTROL VALVE)

75.293

Figure 19-12.–Models of thermostatic valves.



75.294

Figure 19-13.—Identification on thermostatic valve bonnets.

MAINTENANCE OF VENTILATION EQUIPMENT

Shipboard ventilation must serve not only to supply, circulate, and distribute fresh air, but also to remove the used, contaminated, and overheated air from the various spaces. If the ventilation equipment fails to perform its functions properly, conditions may be created which will jeopardize the health or life of crew members. Therefore, the individuals responsible for inspection and maintenance must be thoroughly familiar with the ventilation equipment.

A shipboard ventilation system and its constituent parts cannot be isolated and separated from other component systems in a complete air conditioning system. For example, the air duct distribution system of a ship may be used for other systems in cooling, heating, and dehumidifying the ship's atmospheric air. In addition to ducts, a ventilation system may include weather openings, screens, filters, fans, gratings, closures, heaters, cooling coils, venturi tubes, dampers, and terminals. Obviously, if a ventilation system is to function effectively, it is essential that all of its various units be kept clean and in satisfactory operating condition. To maintain a ventilating system in the best condition requires the observance of applicable precautionary measures and the adherence to prescribed maintenance procedures.

Guarding Against Obstructions to Ventilation

Such items as swabs, deck gear, and trash stowed in fan rooms or ventilation trunks not only restrict airflow but also increase dirt and odors taken inboard. Ventilation terminals must NEVER be used for stowage. Wet clothing secured to ventilation terminals increases the moisture content of the compartment air and restricts the airflow. Stowage arrangements should be such that ventilation weather openings are NEVER restricted.

Keeping the System Clean

Dirt accumulation in a ventilation system not only restricts the flow of air but also creates a serious fire hazard. In a clean duct the cooling effect of the metal tends to act as a flame arrester, but an accumulation of foreign matter within a duct becomes a potential source of combustion. One method of reducing the amount of dirt and combustible matter, which may be carried into a ventilation system, is to wet down the areas in the vicinity of the air intakes before sweeping.

Since a great volume of air passes through or over the elements of a ventilation system, dirt will collect in the various units in spite of precautionary measures. The greatest accumulation of dirt will be within trunks and ducts where it is not readily noticeable. Therefore, periodic inspections and a definite service procedure are necessary to keep the system clean.

CHAPTER 20

ADDITIONAL AUXILIARY EQUIPMENT

In addition to the auxiliary machinery described in previous chapters of the manual, there are a number of other units of machinery which are essential to the operation of a ship and which are directly or indirectly of concern to you as an Engineman. Such auxiliary machinery includes steering gears, anchor windlasses, deck winches, capstans, cranes and auxiliary boilers. Some of this machinery may be located within the engineering spaces of the ship, but many of the units are located outside the engineering spaces.

This chapter provides information on auxiliary machinery with which you will be primarily concerned.

ELECTROHYDRAULIC DRIVE MACHINERY

Hydraulic units are used for driving or controlling steering gears, windlasses, winches, capstans, airplane cranes, ammunition hoists, and distant control valves. This chapter contains information on some hydraulic units with which Enginemen are concerned.

The electrohydraulic type of drive very efficiently meets the operating requirements of modern naval machinery. Some of the major advantages of electrohydraulic machinery are that:

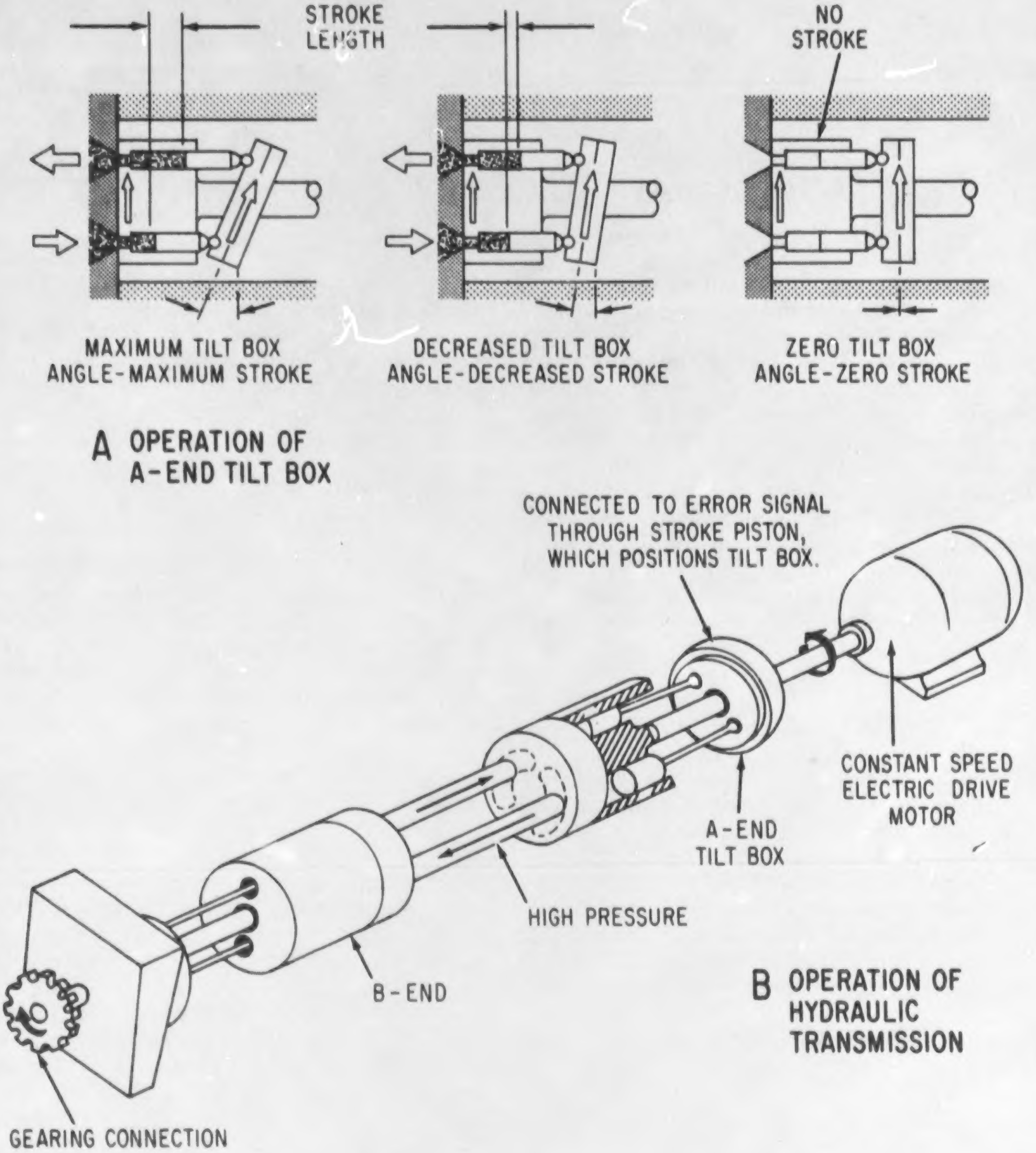
1. Tubing, which can readily transmit fluids around corners, is used to conduct the liquid which transmits the force.
2. Very little space is required for tubing.
3. It allows flexibility in location of components.
4. Operation at variable speeds is possible.
5. Close control of speeds from minimum to maximum limits is allowed.
6. It can be shifted from no load to full load rapidly without damage to machinery.
7. It accelerates quickly.
8. It has a high efficiency.
9. It has a favorable power to weight ratio.

ELECTROHYDRAULIC SPEED GEAR

The unit most frequently used in electrohydraulic applications is the electrohydraulic speed gear. Different variations of the basic design are used for specific applications but the principles remain the same. Basically, the unit consists of an electric motor-driven hydraulic pump (A-end) and a hydraulic motor (B-end). See Chapter 15 of this manual for a discussion on axial piston variable-stroke pumps.

The B-end (fig. 20-1) is already on stroke, and will be made to rotate by the hydraulic force of the oil acting on the pistons. Movement of the pistons' A-end is controlled by a tilt box in which the socket ring is mounted, as shown in part A of figure 20-1.

The length of piston movement is controlled by movement of the tilt box, one way or the other and by the amount of angle at which the tilt box is placed. The length of the piston movement controls the amount of fluid flow. When the drive motor is energized, the A-end is always in motion, but with the tilt box in a neutral or vertical position, there is no reciprocating motion of the pistons, so no oil is pumped to the B-end. Any movement of the tilt box, regardless of how slight, causes pumping action to start, which causes immediate action in


STROKE LENGTH
NO STROKE
MAXIMUM TILT BOX ANGLE-MAXIMUM STROKE
DECREASED TILT BOX ANGLE-DECREASED STROKE
ZERO TILT BOX ANGLE-ZERO STROKE
A OPERATION OF A-END TILT BOX
CONNECTED TO ERROR SIGNAL THROUGH STROKE PISTON, WHICH POSITIONS TILT BOX.
CONSTANT SPEED ELECTRIC DRIVE MOTOR
A-END TILT BOX
HIGH PRESSURE
B-END
B OPERATION OF HYDRAULIC TRANSMISSION
GEARING CONNECTION

83.81

Figure 20-1.—Electrohydraulic speed gear.

463

the B-end, due to the transmission of force by the hydraulic fluid.

When reciprocating motion is desired, such as in a steering gear, the B-end is replaced by a piston or ram. The force of the hydraulic fluid causes the movement of the piston or ram. The tilt box in the A-end can be controlled either locally (as on the anchor windlass) or by remote control (as on the steering gear).

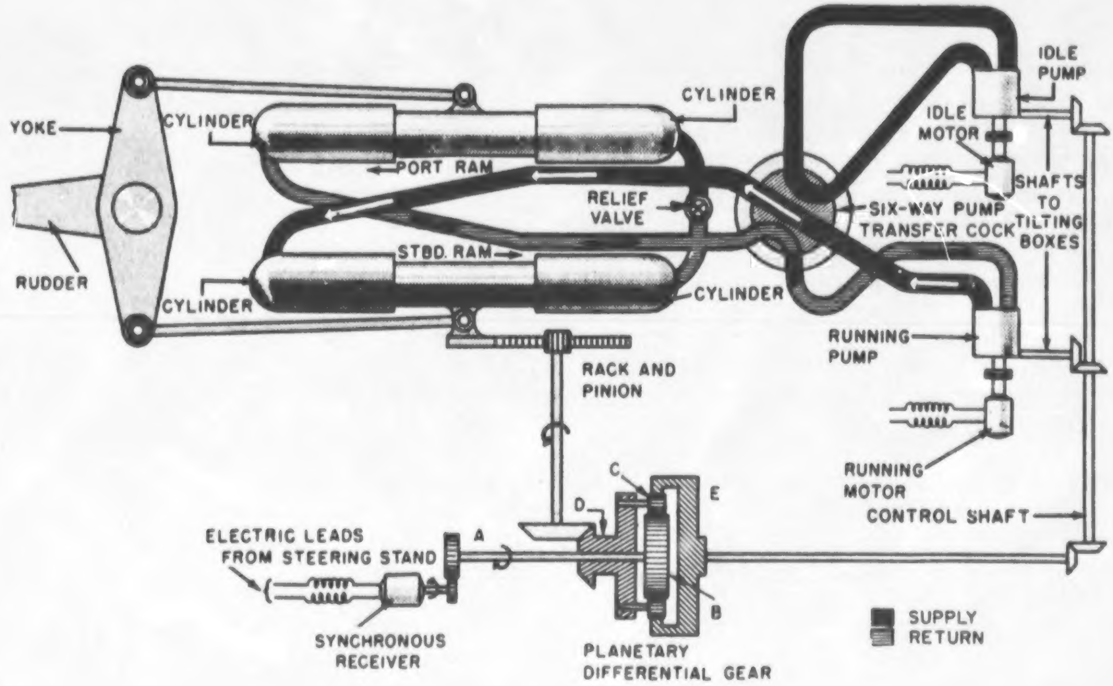
ELECTROHYDRAULIC STEERING GEAR

Most steering gear installations in modern naval ships are the electrohydraulic type and use only the A-end of the previously described electrohydraulic drive. The electrohydraulic steering gear was developed to handle the large momentary power requirements for the electromechanical steering gears–particularly for ships of large displacement and high speed. Also the elimination of direct current power from ships' steering systems made switching and speed control of electric motors more difficult.

Operation of Electrohydraulic Steering Gear

Figure 20-2 shows a simple diagrammatic arrangement of a double-ram type electrohydraulic steering gear. The rudder yoke is connected to two hydraulic plungers or rams. Each ram has cylinders at both ends. The pressure of the hydraulic fluid in the closed system is maintained by one of two rotary, positive-displacement, variable-stroke pumps. Fluid delivery is regulated by the angle of the tilting block in the hydraulic pump, which in turn is controlled either electrically or hydraulically from the steering wheel on deck.

The control shaft and gear are indicated in figure 20-2. Note that the forward port and after


IDLE PUMP
CYLINDER
YOKE
CYLINDER
IDLE MOTOR
PORT RAM
RELIEF VALVE
SHAFTS TO TILTING BOXES
SIX-WAY PUMP TRANSFER COCK
STBD. RAM
RUDDER
CYLINDER
CYLINDER
RUNNING PUMP
RACK AND PINION
RUNNING MOTOR
C
D
E
CONTROL SHAFT
ELECTRIC LEADS FROM STEERING STAND
A
B
■ SUPPLY
▨ RETURN
SYNCHRONOUS RECEIVER
PLANETARY DIFFERENTIAL GEAR

47.139X

Figure 20-2.–Simple diagrammatic arrangement of a double-ram electrohydraulic steering gear.

starboard cylinders are interconnected, as are the forward starboard and after port cylinder. A double-acting relief valve bypasses the fluid from the supply (or discharge) to the return (or suction) line, thus relieving the piping from excessive strain, in case unusual resistance to the rudder (caused by wave action or by jamming) causes abnormal pressures. The motors run at constant speed. Examples of steering gear operation follow.

Starting with a neutral position of the tilting block and no oil flow, suppose the steering wheel is turned to starboard. The turning of the wheel on the bridge sends an electric signal to the synchronous receiver in the steering gear room. The synchronous receiver will then turn correspondingly (counterclockwise in fig. 20-2 as viewed from the left). Shaft A turns clockwise, carrying gear B with it. Gear C meshes with gear B, and internal gear teeth on E turn counterclockwise. E turns the control shaft, which operates the tilting block on the pumps. A quantity of oil now flows to the forward port and after starboard cylinders, causing the rudder to move to the right.

When the steering wheel and the synchronous receiver stop moving, the starboard ram, in moving forward, operates the rack and pinion and turns gear D clockwise. Gear B and shaft A are held by the now motionless synchronous receiver and gear C and casing E turn clockwise, thus returning the tilting block to the neutral position and stopping the flow of oil. The planetary differential gear operates as a followup mechanism. If the steering wheel is turned to port, the actions described will be in the OPPOSITE direction.

Actual installations use two sets of synchronous receivers and two sets of electric motors and pumps for reliability and flexibility. A six-way plug cock makes it possible to transfer quickly from the operating pumps to the standby pumps.

The single-ram type of electrohydraulic steering gear, shown in figure 20-3, operates on the same principle as the double-ram type. The only difference is that there is but one ram, with port and starboard cylinders, mounted athwartship. As the port plunger is forced to move by the pressure of oil against it, the starboard plunger moves correspondingly and forces the same amount of oil out of the starboard cylinder.

Control of Steering Gears

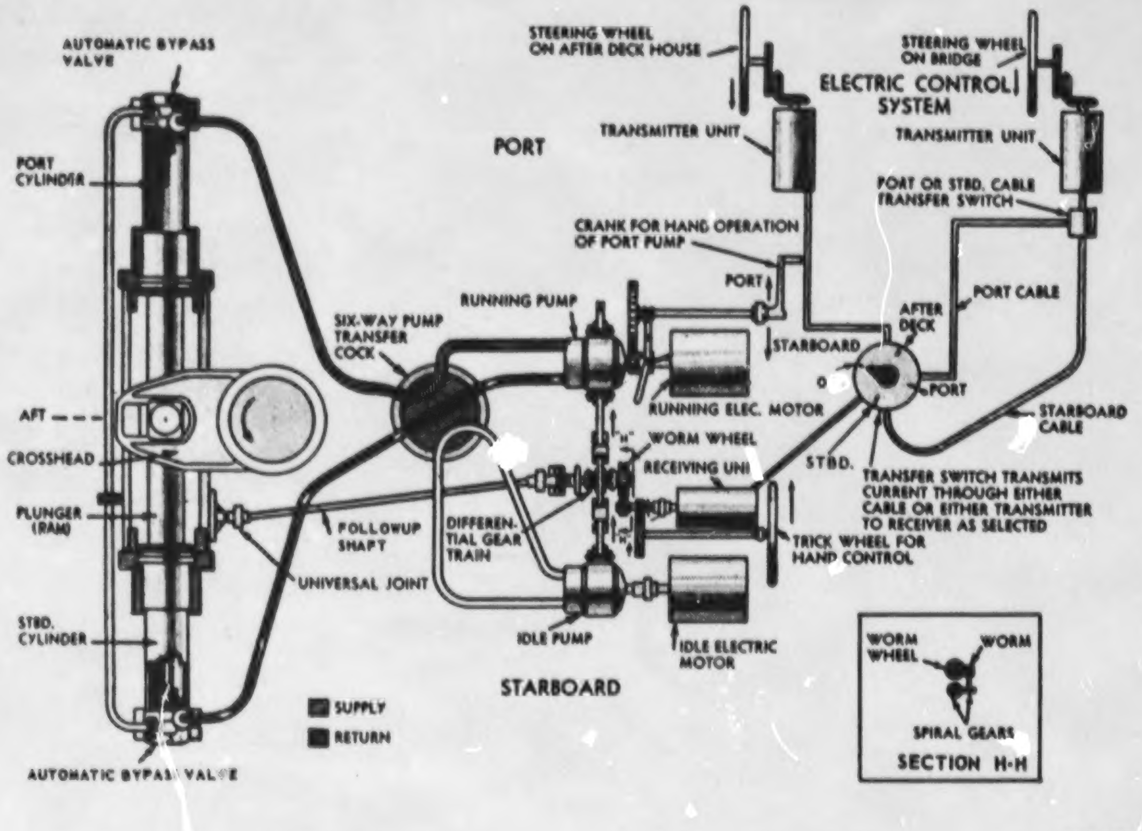
The steering gear can be controlled from the steering wheel on the bridge by any of the following remote control systems, although most modern naval ships use the first one:

1. ELECTRICALLY by an alternating current synchronous transmission system.
2. HYDRAULICALLY by a hydraulic telemotor system.
3. ELECTRICALLY by a direct-current pilot motor and its controller.
4. MECHANICALLY by a shafting or wire rope from the steering station (auxiliary hand operation).

ALTERNATING CURRENT SYNCHRONOUS TRANSMISSION.–The alternating current synchronous transmission type of remote control consists of receiving and transmitting units which are similar to small motors; these are connected to the same a.c. supply. When the transmitter rotor is turned, the receiver turns at the same speed and in the same direction.

The transmitters are located in steering stands at remote control stations and are mechanically connected through gearing to the wheels. A transmitter at one of the remote stations is electrically connected to a receiver in the steering room. The receiver is connected to the control shaft of the variable-displacement hydraulic pump through a differential. Where there is more than one remote steering station, a switch is used to select the desired control station. Indicating lights on the steering stands and at the selector switch indicate which is the selected circuit and that power is available.

HYDRAULIC TELEMOTOR CONTROL.–The hydraulic telemotor type of


AUTOMATIC BYPASS VALVE
PORT CYLINDER
AFT
CROSSHEAD
PLUNGER (RAM)
STBD. CYLINDER
AUTOMATIC BYPASS VALVE
PORT
SIX-WAY PUMP TRANSFER COCK
RUNNING PUMP
FOLLOWUP SHAFT
DIFFERENTIAL GEAR TRAIN
UNIVERSAL JOINT
IDLE PUMP
STARBOARD
SUPPLY
RETURN
STEERING WHEEL ON AFTER DECK HOUSE
TRANSMITTER UNIT
STEERING WHEEL ON BRIDGE
ELECTRIC CONTROL SYSTEM
TRANSMITTER UNIT
PORT OR STBD. CABLE TRANSFER SWITCH
CRANK FOR HAND OPERATION OF PORT PUMP
PORT
STARBOARD
PORT CABLE
AFTER DECK
0
PORT
RUNNING ELEC. MOTOR
STARBOARD CABLE
"H"
WORM WHEEL
RECEIVING UNIT
STBD.
TRANSFER SWITCH TRANSMITS CURRENT THROUGH EITHER CABLE OR EITHER TRANSMITTER TO RECEIVER AS SELECTED
"H"
TRICK WHEEL FOR HAND CONTROL
IDLE ELECTRIC MOTOR
WORM WHEEL
WORM
SPIRAL GEARS
SECTION H-H

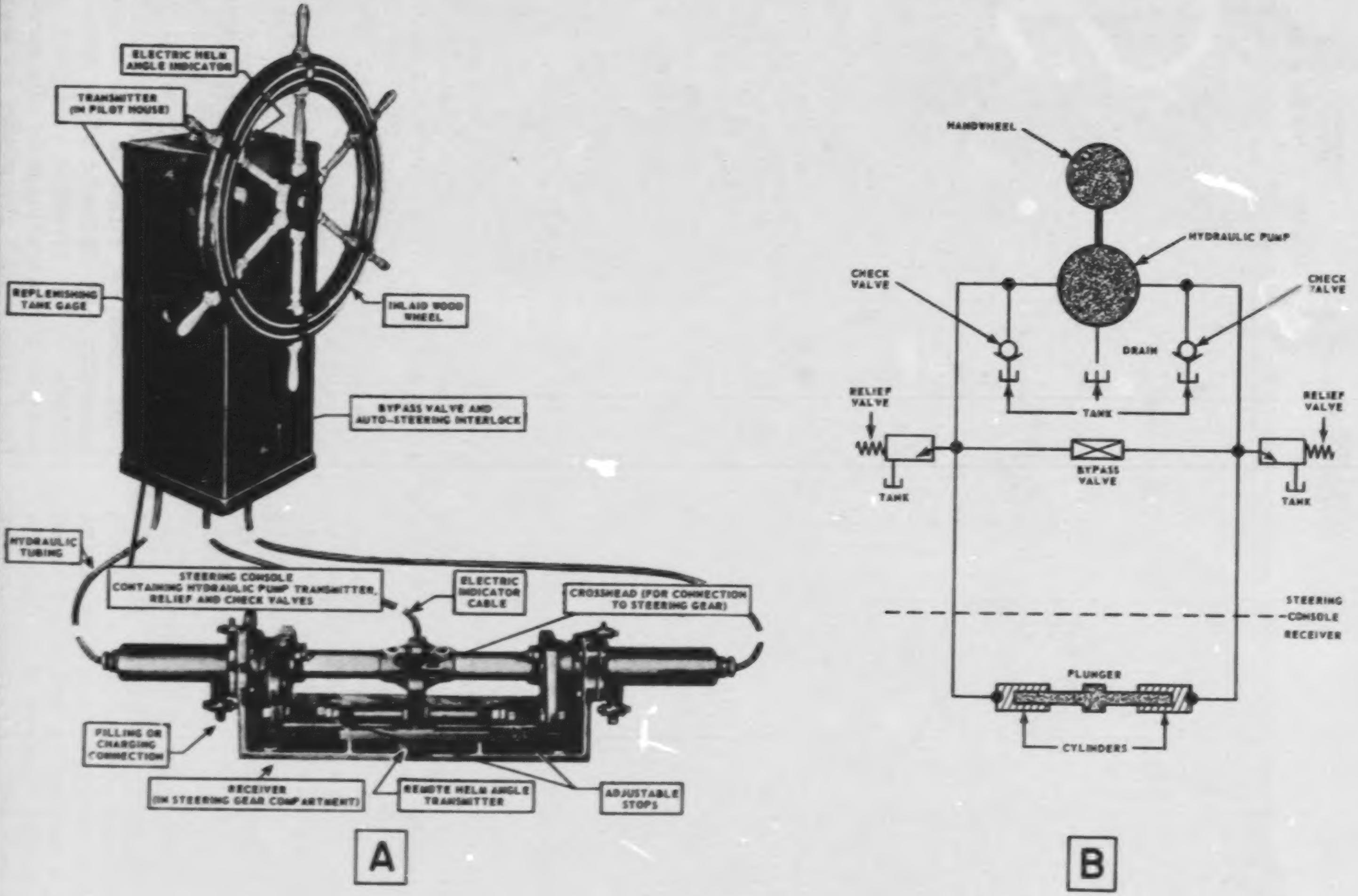
27.83X

Figure 20-3.—Diagrammatic arrangement of a single-ram electrohydraulic steering gear.

remote control (fig. 20-4) is found in many Navy auxiliary ships that are equipped with electrohydraulic steering engines. The system consists of a steering console (hydraulic transmitter) in the pilothouse, a hydraulic receiver in the steering gear compartment, and connecting hydraulic tubing. In addition, an electric cable connects the helm angle transmitter on the receiver housing with the helm angle indicator on the steering console.

A hydraulic transmitter is located inside the steering console under the steering wheel. The hydraulic transmitter components consist of a pump, hydraulic tubing, two relief valves, two check valves, a replenishing tank, and a bypass valve. The remote receiver is a hydraulic plunger-type unit with two cylinders—one on each end of the receiver housing—in axial alignment. A double-acting plunger operates in the cylinders. On the middle portion of this plunger a crosshead is connected for mechanical linkage to the steering gear control mechanism.

The direction of the hydraulic fluid movement depends on the direction of rotation of the steering wheel. Rotation of the steering wheel actuates bevel and spur gears which in turn operate a reversible, hydraulic, axial-piston type pump. The operating principles of this pump are similar to those of the variable-stroke pump, described earlier in this chapter, in connection with hydraulic power transmission systems. In the reversible axial-piston pump, however, the socket ring is set permanently at a fixed angle so that the pistons are always on


ELECTRIC HELM ANGLE INDICATOR
TRANSMITTER (IN PILOT HOUSE)
REPLENISHING TANK GAGE
INLAID WOOD WHEEL
BYPASS VALVE AND AUTO-STEERING INTERLOCK
HYDRAULIC TUBING
STEERING CONSOLE CONTAINING HYDRAULIC PUMP TRANSMITTER, RELIEF AND CHECK VALVES
ELECTRIC INDICATOR CABLE
CROSSHEAD (FOR CONNECTION TO STEERING GEAR)
FILLING OR CHARGING CONNECTION
RECEIVER (IN STEERING GEAR COMPARTMENT)
REMOTE HELM ANGLE TRANSMITTER
ADJUSTABLE STOPS
A
HANDWHEEL
HYDRAULIC PUMP
CHECK VALVE
CHECK VALVE
DRAIN
TANK
RELIEF VALVE
RELIEF VALVE
BYPASS VALVE
TANK
TANK
STEERING
CONSOLE
RECEIVER
PLUNGER
CYLINDERS
B

47.124.1X

Figure 20-4.—Hydraulic telemotor control. A. Telemotor components. B. Hydraulic circuit diagram.

stroke. When the pump shaft and cylinder barrel are rotated by the steering wheel, the pistons draw fluid in from one hydraulic fluid line and discharge it to the other hydraulic fluid line. Reversing the rotation of the steering wheel reverses the direction of fluid flow through the pump. The pump has external check valves and piping for replenishing the hydraulic system from the tank. Relief valves and a bypass valve are also included, as well as vents for purging the system.

When the hydraulic pump shaft is rotated in one direction, the fluid output is discharged from one side of the pump to one of the receiver cylinders. In the other cylinder, hydraulic fluid is displaced to the hydraulic pump. Thus, the hydraulic fluid under pressure moves the receiver plungers and produces a linear movement of the crosshead. This motion is transmitted to the connected steering gear control mechanism. Travel of the crosshead and plungers is limited by adjustable stops on the receiver housing. In figure 20-5, the solid arrows show direction of action for right rudder while the broken arrows show the flow of hydraulic fluid for right rudder.

Air cocks and filling or charging connections are on the receiver cylinders for venting, filling, or purging the hydraulic system.

Filling the Telemotor System.–Fill the telemotor system from the charging tank by opening the air cocks at the forward telemotor and starting the charging pump. After the oil appears at the air cocks, continue pumping until the oil is free of bubbles. Next, close the air cocks and allow the oil to fill the replenishing tank. While the pump is still operating, close the valve leading to the replenishing tank at which time the system will be subjected to a slight pressure.

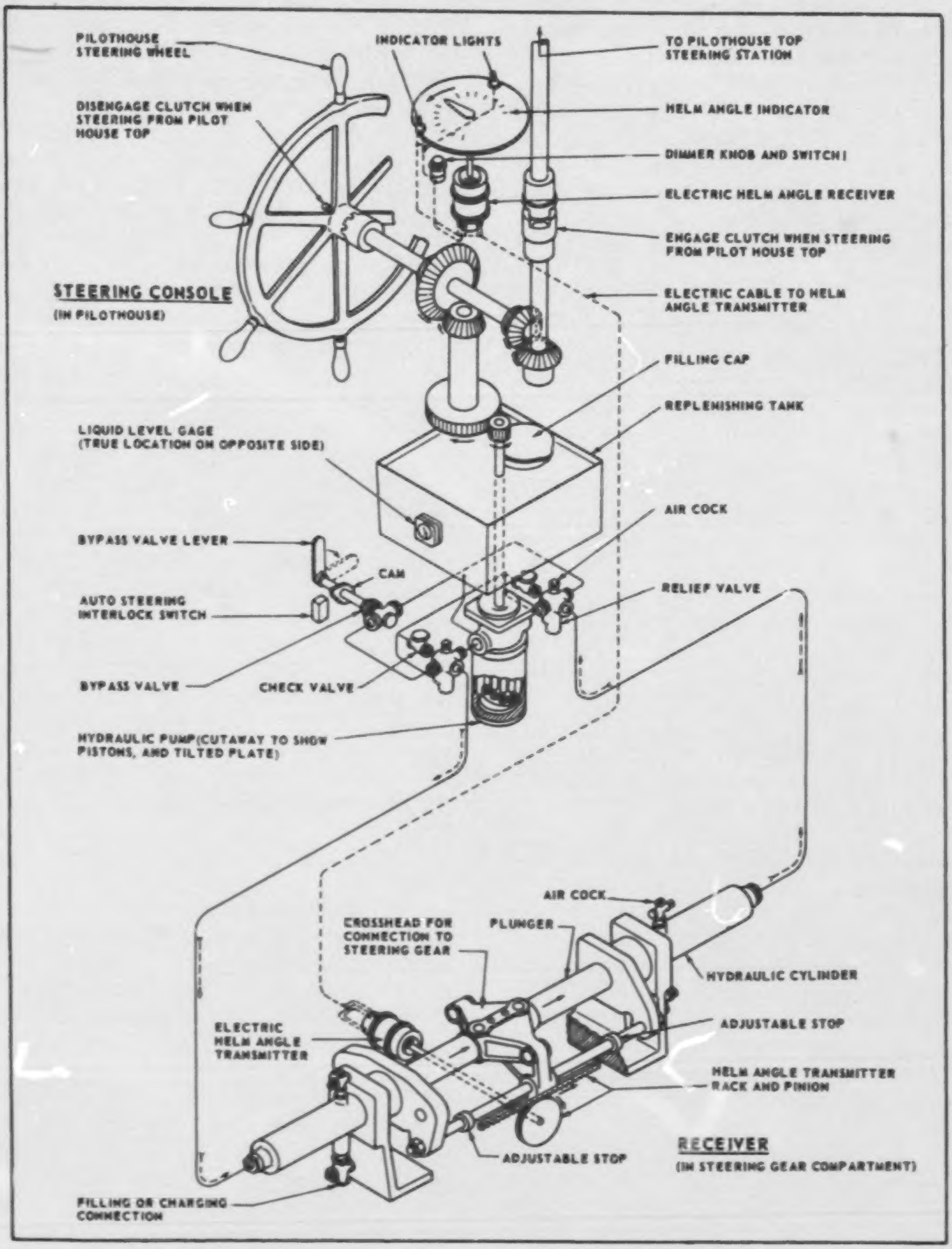
Purging Entrapped Air.–The effective operation of the telemotor system depends upon the purging of all entrapped air and the elimination of leaks. To purge the system of air, under normal operating conditions, open the valve leading from the replenishing tank and the air cocks at the forward telemotor. Because the replenishing tank is located above the highest point of the telemotor system, the air is forced out of the air cocks by the gravity flow of the oil. Then close the cocks when the oil flows smoothly without bubbles.

To detect and eliminate leaks in the system, inspect the valves and joints frequently. To correct a leaky piston in the internally packed telemotor, see that the leathers are in good condition and that the springs (if used) keep the leather in contact with the inside wall of the telemotor cylinders. To stop leaks in the externally packed telemotor, tighten the glands just enough to cause the packing to be compressed about the rams, until the leak is stopped.

Hydraulic Fluid Characteristics.–The hydraulic fluid characteristics are especially important when the telemotor system is exposed to low ambient temperatures. Under such conditions, a high grade mineral oil that has a cold pour point of -25° to -40°F (-32° to -40°C) should be used. Where low temperatures are not involved or where special oil with the designated cold pour point cannot be readily obtained, the symbol 2075H oil may be used satisfactorily. The oil should have a low rate of expansion and be sufficiently viscous at 150°F (66°C) to remain a good hydraulic fluid.

Filling the Charging Tank.–When filling the charging tank with hydraulic fluid, strain the oil into the tank through a funnel which has a fine mesh screen. This prevents the entry of foreign matter and at the same time prevents the entry of air bubbles into the hydraulic system. The oil should never be allowed to become contaminated with water.

DIRECT CURRENT PILOT MOTOR CONTROL.–The direct current pilot motor type of remote control is used with some early electrohydraulic steering gears. It consists of a small, reversible direct current motor, which is connected through a differential gear to the control shaft of a variable-stroke pump. The pilot motor is controlled by a magnetic control panel located next to the motor and with a master controller located at the steering wheel.


PILOTHOUSE STEERING WHEEL
INDICATOR LIGHTS
TO PILOTHOUSE TOP STEERING STATION
DISENGAGE CLUTCH WHEN STEERING FROM PILOT HOUSE TOP
HELM ANGLE INDICATOR
DIMMER KNOB AND SWITCH
ELECTRIC HELM ANGLE RECEIVER
ENGAGE CLUTCH WHEN STEERING FROM PILOT HOUSE TOP
STEERING CONSOLE
(IN PILOTHOUSE)
ELECTRIC CABLE TO HELM ANGLE TRANSMITTER
FILLING CAP
REPLENISHING TANK
LIQUID LEVEL GAGE (TRUE LOCATION ON OPPOSITE SIDE)
AIR COCK
BYPASS VALVE LEVER
CAM
RELIEF VALVE
AUTO STEERING INTERLOCK SWITCH
BYPASS VALVE
CHECK VALVE
HYDRAULIC PUMP(CUTAWAY TO SHOW PISTONS, AND TILTED PLATE)
AIR COCK
CROSSHEAD FOR CONNECTION TO STEERING GEAR
PLUNGER
HYDRAULIC CYLINDER
ADJUSTABLE STOP
ELECTRIC HELM ANGLE TRANSMITTER
HELM ANGLE TRANSMITTER RACK AND PINION
RECEIVER
(IN STEERING GEAR COMPARTMENT)
ADJUSTABLE STOP
FILLING OR CHARGING CONNECTION

47.124.2X

Figure 20-5.—Schematic diagram of hydraulic telemotor components.

The motor has a magnetic brake which stops and holds the motor when the master controller is returned to the neutral position.

AUXILIARY HAND OPERATION.–Auxiliary hand gear is provided for most ships that have electrohydraulic steering gears. This auxiliary hand gear usually consists of a hand-operated hydraulic pump supplemented by chain hoists.

The hydraulic emergency steering system consists of a relief valve, shuttle valve, hand-operated dual hydraulic pump, associated piping, valves, and fittings. The piping from the emergency pump to the main hydraulic system is arranged so that the high-pressure stop valves can be closed to prevent leakage through the main hydraulic units from the pressure developed by the hand pumps. The emergency pump is usually connected to the main hydraulic system, permitting the use of all four ram cylinders. If the emergency pump is not connected in this manner, it is necessary to reduce the speed of the ship in order to limit the ram pressure to that permitted by the pump design. Since it is necessary to block off the emergency system under normal steering gear operation, the emergency lines are generally connected to the drain valves; this eliminates the necessity of additional high-pressure valves.

As the emergency steering system described above depends on an intact hydraulic system for operation, rudder positioning equipment to permit steering with the propellers (after all other means of steering have been rendered inoperable) is also furnished. This equipment consists of chain hoists and suitable attachments for moving the rudder with the ship dead in the water.

Maintenance of Electrohydraulic Steering Gears

The maintenance required for most electrohydraulic steering gears is shown on the Maintenance Index Page, figure 20-6. In addition to this maintenance, it is important that the exposed parts of the steering gear rams be protected against water and damage from rolling or falling objects. Cover them with a thin film of rust preventive compound or a heavy oil. To protect the exposed parts from rolling objects, place a guard over the parts, and keep the steering gear compartment clear of loose gear at all times.

Steering Engineroom Watch

As an Engineman, you may be required to stand watch in the steering engineroom. The duties of the steering engineroom watch include operation, care, and emergency repair of the machinery in your charge. Operating instructions and system diagrams are posted in the steering engineroom. The diagrams describe the various methods of operating the steering gear under normal and emergency conditions and show the relative positions of the valves concerned for each method of operation.

During your watch in the steering engineroom:

1. Make sure that the standby equipment is ready for instant use in an emergency.

2. Inspect the steering gear thoroughly. Check the unit by feeling the various parts. Report any part that feels "HOT" to the bare hand to the officer of the deck on the bridge and to the officer of the watch in the engineroom.

3. Investigate for binding, overloading, and lack of lubrication.

4. Listen for new or unusual noises which may indicate loose parts or wear.

5. Bleed all air out of the system.

6. Check for leaks in the line and fittings. Piping leaks usually occur following unusual strain (as from rough seas). Most leaks can be corrected by tightening the flange bolts. Small leaks at ram packing glands are not objectionable since the small flow of hydraulic

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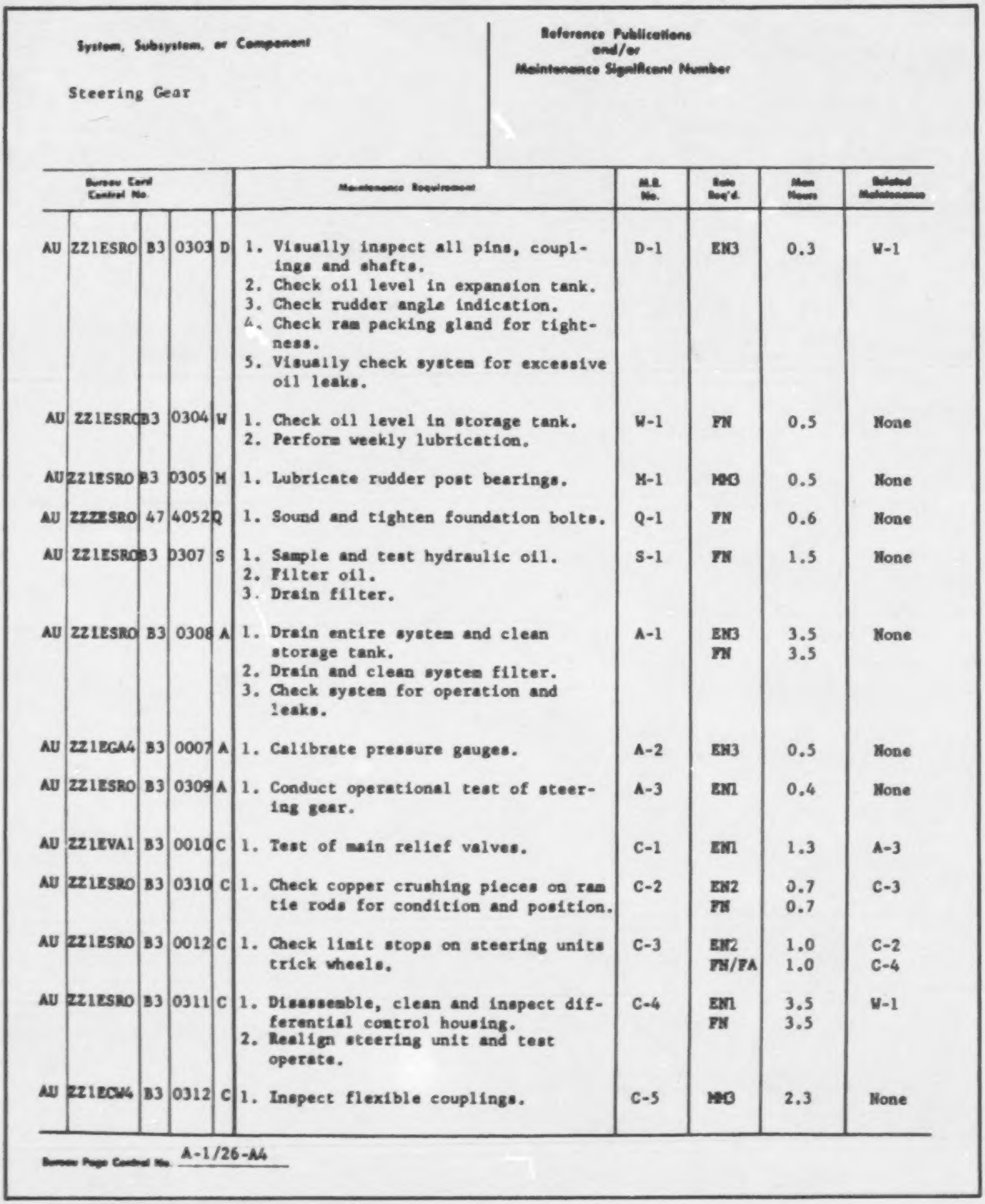


System, Subsystem, or Component

Steering Gear

Reference Publications and/or Maintenance Significant Number

Bureau Card Control No.					Maintenance Requirement	M.R. No.	Rate Req'd.	Man Hours	Related Maintenance
AU	ZZ1ESRO	B3	0303	D	1. Visually inspect all pins, couplings and shafts. 2. Check oil level in expansion tank. 3. Check rudder angle indication. 4. Check ram packing gland for tightness. 5. Visually check system for excessive oil leaks.	D-1	EN3	0.3	W-1
AU	ZZ1ESRO	B3	0304	W	1. Check oil level in storage tank. 2. Perform weekly lubrication.	W-1	FN	0.5	None
AU	ZZ1ESRO	B3	0305	M	1. Lubricate rudder post bearings.	M-1	MM3	0.5	None
AU	ZZZESRO	47	4052	Q	1. Sound and tighten foundation bolts.	Q-1	FN	0.6	None
AU	ZZ1ESRO	B3	0307	S	1. Sample and test hydraulic oil. 2. Filter oil. 3. Drain filter.	S-1	FN	1.5	None
AU	ZZ1ESRO	B3	0308	A	1. Drain entire system and clean storage tank. 2. Drain and clean system filter. 3. Check system for operation and leaks.	A-1	EN3 FN	3.5 3.5	None
AU	ZZ1EGA4	B3	0007	A	1. Calibrate pressure gauges.	A-2	EN3	0.5	None
AU	ZZ1ESRO	B3	0309	A	1. Conduct operational test of steering gear.	A-3	EN1	0.4	None
AU	ZZ1EVA1	B3	0010	C	1. Test of main relief valves.	C-1	EN1	1.3	A-3
AU	ZZ1ESRO	B3	0310	C	1. Check copper crushing pieces on ram tie rods for condition and position.	C-2	EN2 FN	0.7 0.7	C-3
AU	ZZ1ESRO	B3	0012	C	1. Check limit stops on steering units trick wheels.	C-3	EN2 FN/FA	1.0 1.0	C-2 C-4
AU	ZZ1ESRO	B3	0311	C	1. Disassemble, clean and inspect differential control housing. 2. Realign steering unit and test operate.	C-4	EN1 FN	3.5 3.5	W-1
AU	ZZ1ECW4	B3	0312	C	1. Inspect flexible couplings.	C-5	MM3	2.3	None

Bureau Page Control No. A-1/26-A4

98.171

Figure 20-6.—Planned Maintenance Index Page, steering gear.

fluid provides lubrication. Always maintain sufficient fluid in the tanks.

7. Check and ensure that all grease fittings and surfaces requiring lubrication are lubricated in accordance with the instructions on the lubrication chart.

8. Observe all applicable safety precautions. Keep oil off the deck. Exercise extreme caution when working in the confined spaces around the rams and actuating gear. All clothing should be free of loose ends that might catch in the machinery.

WEIGHT-HANDLING EQUIPMENT

To qualify for advancement in rating, you must be familiar with the construction, operation, and maintenance of anchor windlasses, cranes, and winches. The discussion of such machinery and other weight-handling equipment, such as capstans and elevators, which follows, is supplementary to that given in *Fireman*, NAVEDTRA 10520.

Anchor Windlasses

In a typical electrohydraulic mechanism, one constant-speed electric motor drives two variable-stroke pumps through a coupling and reduction gear. Other installations include two motors, one for driving each pump. Each pump normally drives one wildcat, although (with the use of 3-way plug cock type valves) either pump may drive either of the two wildcats. The hydraulic motors drive the wildcat shafts by means of multiple spur gearing and a locking head. The locking head permits disconnecting the wildcat shaft, thus permitting free operation of the wildcat, as when dropping anchor.

Each windlass pump is controlled either from the weather deck or locally with handwheels or shafting leading to the pump control. The hydraulic system will require your attention. Be certain that the hydraulic system is always serviced with the specified type of clean oil.

The types of anchor windlasses that an Engineman may have to maintain are normally the electric, electrohydraulic, and the hand-driven windlasses. Hand-driven windlasses are used only on small ships where the weight of the anchor gear is such that it can be handled without excessive effort by operating personnel.

In maintaining a hand windlass, the major factor is to keep the linkage, friction shoes, locking head, and brake in proper adjustment and in satisfactory operating condition at all times. In maintaining an electrohydraulic windlass, your principal concern is the hydraulic system.

Even though used intermittently and only for relatively short periods of time, a windlass must be capable of handling the required load under extremely severe conditions. To prevent deterioration and to provide dependable operation whenever required, maintenance and adjustment must be continued during the periods when the machinery is not in use.

Windlass brakes must be maintained in satisfactory condition if they are to perform their function properly. Because of wear and compression of brake linings, the clearance between the brake drum and band will increase after a windlass has been in operation. Brake linings and clearances should be inspected frequently. Means of adjustment are provided on all windlass brakes. Adjustments should be made in accordance with the manufacturer's instructions.

You should carefully follow the lubrication instructions furnished by the manufacturer. If a windlass has been idle for some time, it should be lubricated before being put into operation. After a windlass has been used, it should be lubricated to protect finished surfaces from corrosion and to prevent seizure of moving parts.

The hydraulic transmissions of electrohydraulic windlasses and other auxiliaries are manufactured with close tolerances between moving and stationary parts. If these tolerances are to be maintained and unnecessary wear is to be prevented, every possible precaution must be taken to prevent the entry of dirt and other abrasive material into the system. When the system is replenished or refilled, only clean oil should be used and it should be strained as it is poured into the tank. If a hydraulic transmission has been disassembled, all parts should be thoroughly cleaned before reassembly. Before piping or valves are installed, their interiors should be cleaned to remove any scale, dirt, preservatives, or other foreign matter.

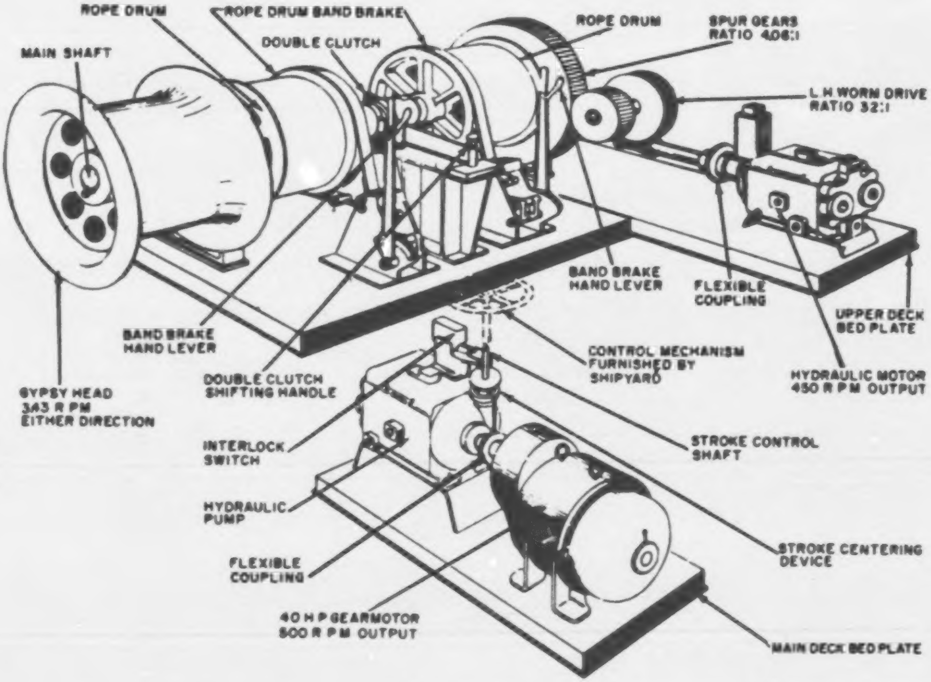
Winches and Capstans

Winches are used for heaving in on mooring lines, hoisting boats, topping lifts on jumbo booms of large auxiliary ships, and for handling cargo. Power for operating shipboard winches is usually furnished by electricity and, on some older ships, by steam. Where delicate control and high acceleration without jerking are required, such as for handling aircraft, electrohydraulic winches are usually installed. Most auxiliary ships are equipped with either electrohydraulic or electric winches.

CARGO WINCHES.–Among the various types of winches for general cargo handling are: double-drum, double-gypsy, and single-drum, single-gypsy units. Four-drum, two-gypsy machines are generally used for minesweeping.

Electrohydraulic Winches.–Electrohydraulic winches (fig. 20-7) are always drum type. The drive equipment is like most hydraulic systems: a constant-speed electric motor drives the A-end (variable-stroke hydraulic pump) which is connected to the B-end (hydraulic motor) by suitable piping. The drum shaft is driven by the hydraulic motor through reduction gearing.

Winches normally have one horizontally mounted drum and one or two gypsy heads. If only one gypsy is required, it may be easily removed from or assembled on either end of the


ROPE DRUM
ROPE DRUM BAND BRAKE
DOUBLE CLUTCH
MAIN SHAFT
ROPE DRUM
SPUR GEARS
RATIO 40.6:1
L H WORM DRIVE
RATIO 32:1
BAND BRAKE
HAND LEVER
FLEXIBLE
COUPLING
UPPER DECK
BED PLATE
BAND BRAKE
HAND LEVER
CONTROL MECHANISM
FURNISHED BY
SHIPYARD
HYDRAULIC MOTOR
450 R P M OUTPUT
GYPSY HEAD
343 R P M
EITHER DIRECTION
DOUBLE CLUTCH
SHIFTING HANDLE
INTERLOCK
SWITCH
STROKE CONTROL
SHAFT
HYDRAULIC
PUMP
STROKE CENTERING
DEVICE
FLEXIBLE
COUPLING
40 H P GEARMOTOR
800 R P M OUTPUT
MAIN DECK BED PLATE

47.145

Figure 20-7.–Electrohydraulic winch units.

drum shaft. When a drum is to be used, it is connected to the shaft by a clutch.

Electric Winches.–An electrically driven winch is shown in figure 20-8. This winch is a single-drum, single-gypsy type. The electric motor drives the unit through a set of reduction gears. A clutch is also provided to engage or disengage the drum from the drum shaft. Additional features include an electric brake and a speed control switch.

CAPSTANS.–To facilitate handling large, heavy mooring lines and wires, capstans are mounted on deck. These capstans may be separate machinery units, as usually seen on tug boats, or they may be part of the anchor windlass, as on most Navy ships.

The essential feature of the capstan is the vertical spool-shaped drum, fitted with pawls. Whelps or ridges on the drum are provided to keep the lines from slipping, especially when wet.

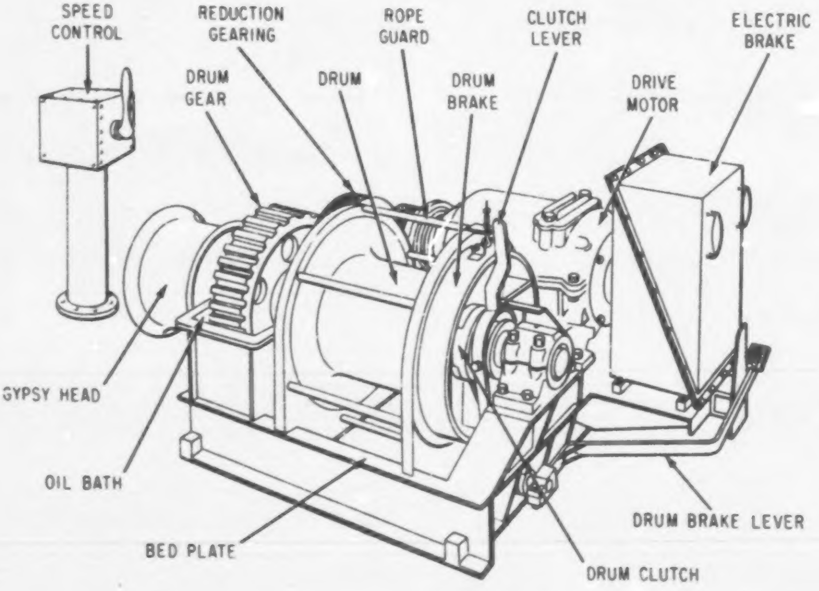
Capstans are powered by either steam or electricity. On small ships (such as minesweepers) they also may be operated by hand, in an emergency, by using bars fitted into the pigeonholes in the capstan head. Depending on the type and size of a ship, capstans may be located any place on the deck.

Electric Capstans.–Electric capstans are usually of the reversible type and develop the same speed and power in either direction. Capstans driven by alternating current motors have two speeds, full speed and one-half speed. Capstans driven by direct current motors usually have from three to five speeds in either direction of rotation.

Steam Capstans.–Steam capstans were formerly used extensively in Navy ships, but they are now used only occasionally where the electric power is insufficient.

Maintenance of Winches and Capstans

In several respects, the maintenance of a winch or a capstan is similar to that for a windlass. Where band brakes are used on the



47.227

Figure 20-8.–Electric winch.

drums, the friction linings should be inspected regularly and replaced when necessary. Steps should be taken to prevent oil or grease from accumulating on the brake drums. The operation of brake-actuating mechanisms, latches, and pawls should be checked periodically.

Winch drums driven by friction clutches should be inspected frequently to determine if deterioration has occurred in the friction material or if oil and grease are preventing proper operation. The sliding parts of positive clutches must be properly lubricated, and the locking device on the shifting gear should be checked to determine if it will hold under load. The oil of gear reduction units should be checked for proper amount, temperature, and purity. Periodic inspections should be made of the pressure lubrication fittings normally installed on slow moving parts. On installations that use hydraulic transmission, the pumps and lines are maintained in the same way as those of any other hydraulic system.

Cranes

Cranes are designed to meet the following conditions:

1. To hoist, lower, top, and rotate rated load at the specified speed and against a specified list of the ship.
2. To handle 150% rated load at no specified speed.
3. To withstand a static suspended load of 200% rated load without damage or distortion to any part of the crane or structure.

The types of cranes installed in ships vary in accordance with the equipment handled. Cranes are classified as general type and type of drive as follows:

1. General Type
   - a. Rotating king post
   - b. Stationary king post
   - c. Pedestal mounted
   - d. Jib
   - e. Traveling
2. Type of drive
   - a. Electrohydraulic
   - b. Electromechanical
   - c. Gasoline engine
   - d. Diesel engine
   - e. Hand operated

The crane equipment generally includes the boom, king post, king post bearings, sheaves, hook and rope, machinery platforms, rotating gear, drums, hoisting, topping and rotating drives, and controls. The important components are described in the paragraphs which follow.

BOOMS.–A boom, used as a mechanical shipboard appliance, is a structural unit for lifting, transferring, or supporting heavy weights. A boom is used in conjunction with other structures or structural members which support it, and various ropes and pulleys, called blocks, which control it.

KING POST BEARINGS.–On stationary king posts, bearings are provided for taking both vertical load and horizontal strain at the collar, located at the top of the king post. On rotating king posts, bearings are provided for both vertical and horizontal loads at the base and for horizontal reactions at a higher deck level.

SHEAVES AND ROPES.–The hoisting and topping ropes are led from the drums over sheaves to the head of the boom. The sheaves and ropes are designed in accordance with recommendations by the Naval Sea Systems Command, which give the criteria for selection of sheave diameter, size, and flexibility of the rope. Sufficient fair-lead sheaves are fitted to prevent fouling of the rope. Electrical insulators may be installed at the hoisting block or sheave at the head of the boom, to take care of shock hazards.

MACHINERY PLATFORMS.–Machinery platforms carry the power equipment and operator's station. These platforms are mounted on the king post above the deck.

ROTATING GEAR AND PINIONS.–Rotation of the crane is accomplished by vertical shafts with pinions engaging a large rotating gear.

DRUMS.–The drums of the hoisting and topping winches are generally grooved for the proper size wire rope. The drums in the latest designs are arranged to stow the rope in one layer to facilitate spooling and to prevent crushing of the rope. The hoisting system is arranged for use with single or multiple part lines as required. The topping system is arranged for use with a multiple purchase as required.

Operation and Maintenance of Cranes

The hoisting whips and topping lifts of cranes are usually driven by hydraulic variable-speed gears through gearing of various types. This provides the wide range of speed and delicate control required for load handling. The cranes are usually rotated by an electric motor connected to worm and spur gearing or by an electric motor and hydraulic variable-speed gear connected to appropriate reduction gearing.

Some electrohydraulic cranes have automatic slack line takeup equipment, consisting of an electric torque motor geared to the drum. When these cranes are used for lifting boats, aircraft, or other loads from the water, the torque motor assists the hydraulic motor drive to reel in the cable in case the load is lifted faster by the water than it is being hoisted by the crane.

Electrohydraulic equipment for the crane consists of one or more electric motors running at constant speed. Each motor drives one or more A-end variable-displacement hydraulic pumps whose strokes are controlled through operating handwheels. START, STOP, and EMERGENCY RUN pushbuttons are located at the operator's station for the control of the electric motors. Interlocks are provided to prevent starting the electric motors when the hydraulic pumps are on stroke. B-end hydraulic motors are connected to the A-end pumps by piping and drive the drums of the hoisting and topping units or the rotating machinery.

Reduction gears are provided between the electric motor and the A-end pump and between the B-end hydraulic motor and the rotating pinion. Each hoisting, topping, and rotating drive has an electric brake on the hydraulic motor output shaft. The electric brake is interlocked with the hydraulic pump control so that the brake will set when the hydraulic control is on neutral or when electric power is lost. A centering device is provided for accurately finding and retaining the neutral position of the hydraulic pump.

Relief valves are installed to protect the hydraulic system. These relief valves are set in accordance with the requirements of Chapter 556 of the *NAVSHIPS' Technical Manual.*

Maintenance of cranes should be in accordance with the Planned Maintenance System requirements or the manufacturers' instructions. In general, the maintenance of electrohydraulic cranes requires that the oil in the replenishing tanks be kept at the prescribed levels and that the system be kept clean and free of air. The limit stop and other mechanical safety devices must be checked regularly for proper operation. When cranes are not in use, they should be secured in their stowed positions, and all electric power to the controllers should be secured.

GALLEY AND LAUNDRY EQUIPMENT

The Navy uses a variety of equipment to perform laundry and galley functions. The type of equipment installed will depend on the size of the ship, the availability of steam, and other factors. For reference, obtain and maintain the equipment manufacturer's technical manual for each different piece of gear aboard. Preventive maintenance is to be scheduled and performed according to the requirements of the 3-M system.

STEAM-JACKETED KETTLES

Steam-jacketed kettles (fig. 20-9) come in a variety of sizes from 5 gallons to 80 gallons. Kettles are made of corrosion-resisting steel. The kettles are constructed to operate at a maximum steam pressure of 45 psi. A relief valve is installed in the steam line leading to the kettles, set to lift at 45 psi. Maintenance on these units is normally limited to maintaining the steam lines and valves associated with the kettles.

Other steam-operated cooking equipment includes steamers (fig. 20-10) and steamtables (fig. 20-11). Steamers use steam at a pressure of 5 to 7 psi; steamtables use steam at a pressure of 40 psi or less.

DISHWASHING EQUIPMENT

Dishwashing machines used in the Navy are classified as one-tank, two-tank, or three-tank

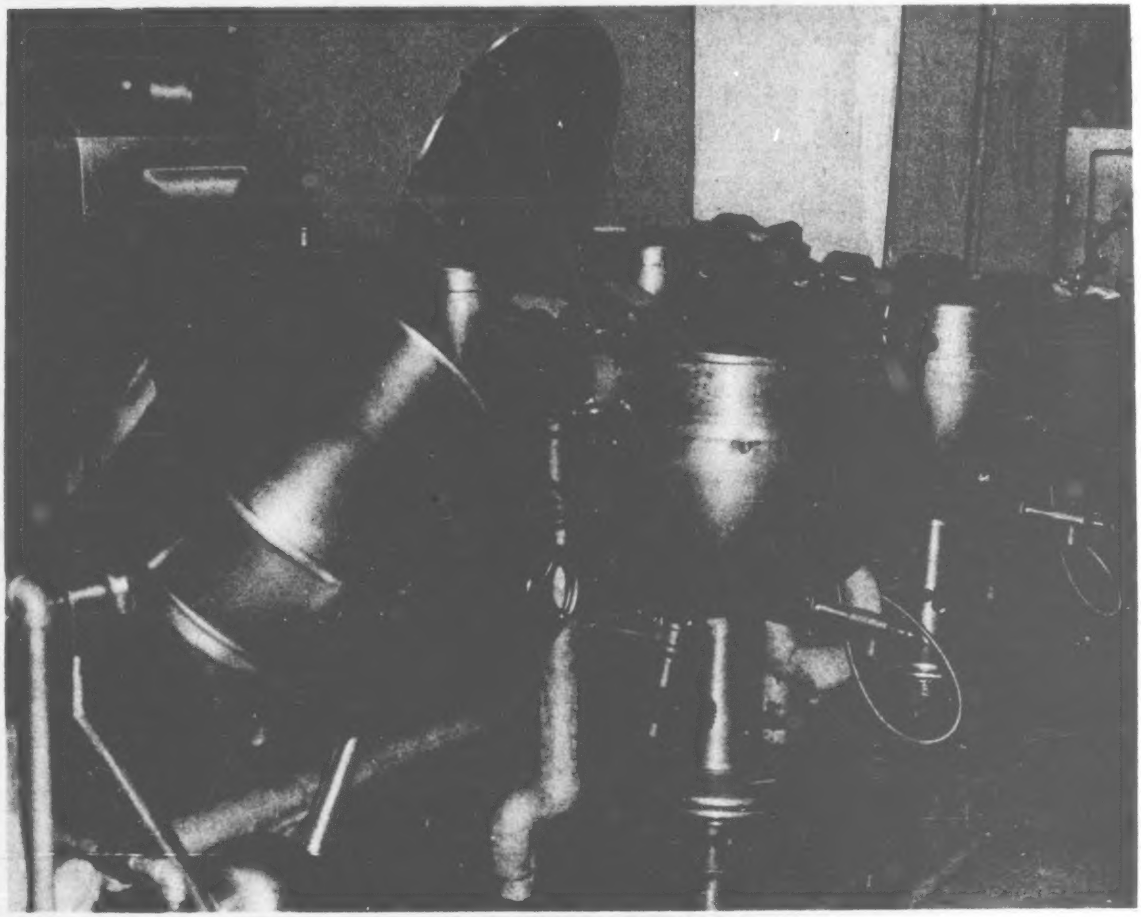


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Figure 20-9.—Steam-jacketed kettles.

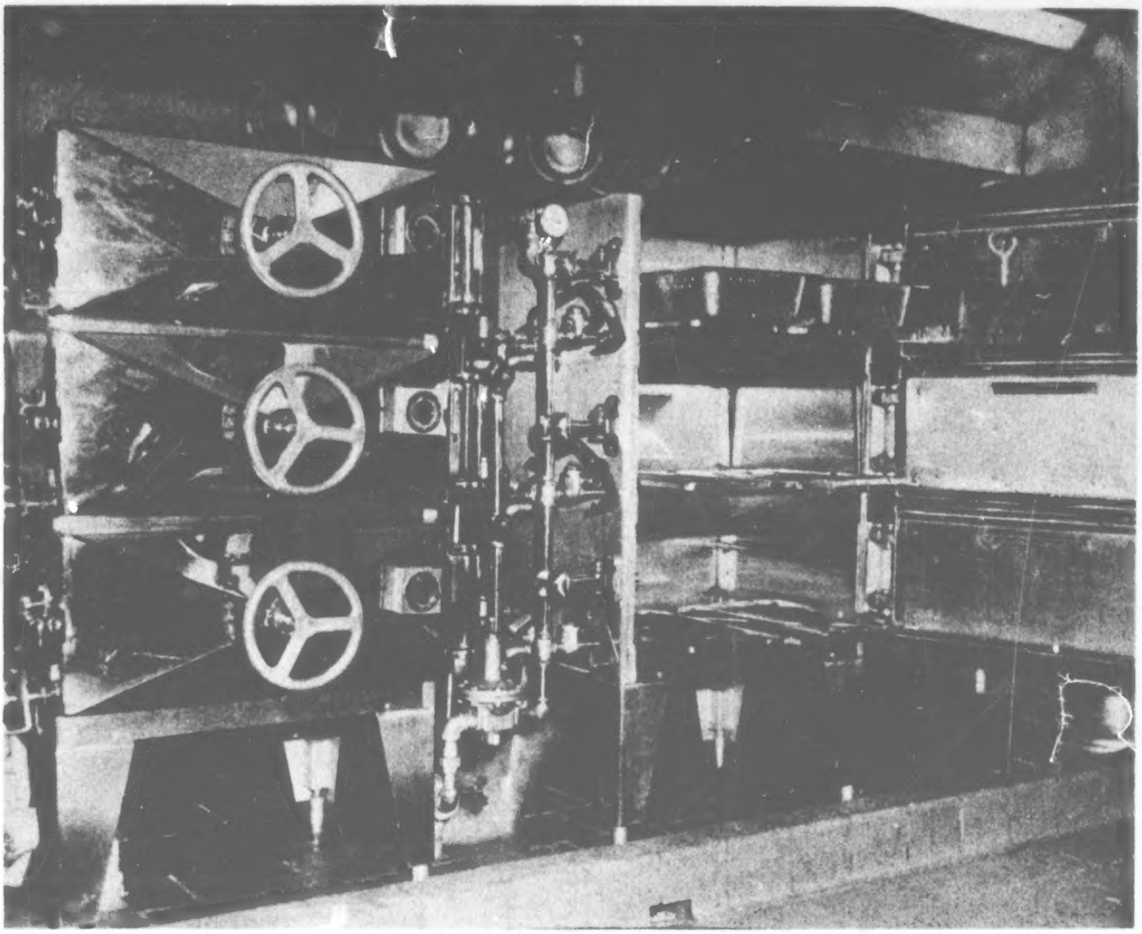

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Figure 20-10.–Steamer.

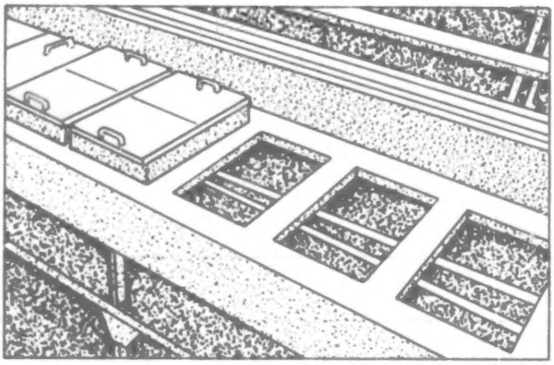

Figure 20-11.–Steamtable. 48.20

machines. The three-tank machine is a fully automatic, continuous racking machine which scrapes, brushes, and provides two rinses. It is used at large activities.

Single Tank

Single tank machines (fig. 20-12) are used in small ships where larger models are not feasible.

To control the bacteria to a satisfactory minimum in single-tank machines, the temperature of the washwater in the tank must be 140°F (60°C). Consequently, a thermostat in

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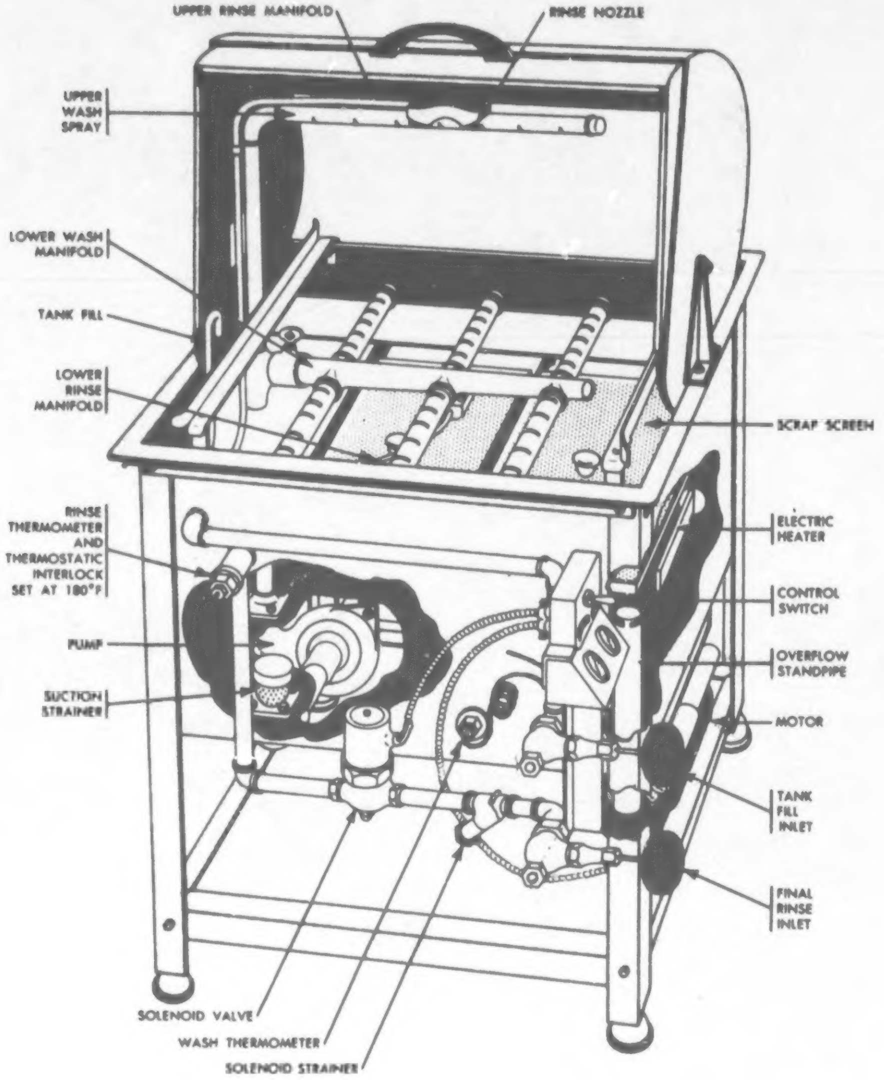

UPPER RINSE MANIFOLD
RINSE NOZZLE
UPPER WASH SPRAY
LOWER WASH MANIFOLD
TANK FILL
LOWER RINSE MANIFOLD
SCRAP SCREEN
RINSE THERMOMETER AND THERMOSTATIC INTERLOCK SET AT 180°F
ELECTRIC HEATER
CONTROL SWITCH
PUMP
OVERFLOW STANDPIPE
SUCTION STRAINER
MOTOR
TANK FILL INLET
FINAL RINSE INLET
SOLENOID VALVE
WASH THERMOMETER
SOLENOID STRAINER

48.34

Figure 20-12.—Typical semiautomatic single-tank dishwashing machine.

the machine prevents operation when the temperature of the water falls below 140°F. Water temperatures higher than 160°F (71°C) result in less efficient removal of certain foods. The washing time in the automatic machines is 40 seconds.

For rinsing, hot water is sprayed on the dishes from an external source and is controlled by an adjustable automatic steam-mixing valve which maintains the rinse water between 180° and 195°F (82° and 90°C).

To conserve freshwater, the rinse time interval is usually limited to 10 seconds. When water supply is not a problem, a rinse of 20 seconds is recommended.

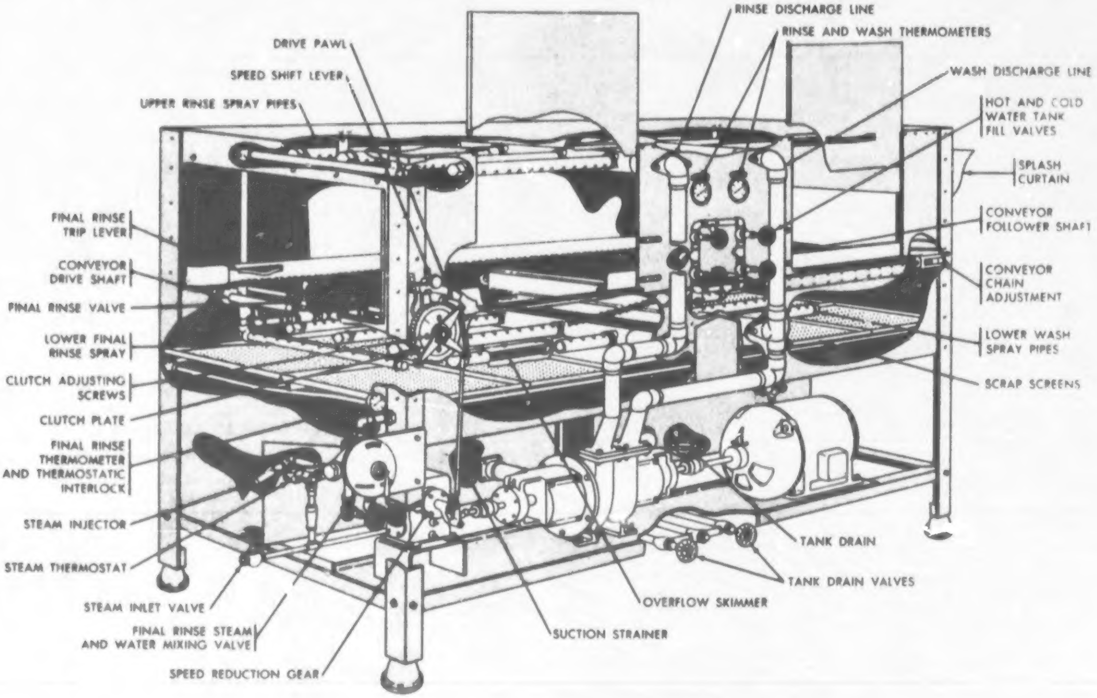
Wash and rinse sprays are controlled separately by automatic, self-opening and closing valves in the automatic machine. The automatic machines provide a 40-second wash and a 10-second rinse.

Double Tank

Double tank machines (fig. 20-13) are available in several capacities and are used when more than 150 persons are to be served at one meal. These machines have separate wash and rinse tanks. They also have a final rinse of hot water which is sprayed on the dishes from an external source. This spray is opened by the racks as they pass through the machines. The spray automatically closes when the rinse cycle is completed. The final rinse is controlled by an adjustable automatic steam mixing valve which maintains the temperature between 180° and 195°F. Double tank machines are also equipped with a thermostatically operated switch in the rinse tank which prevents operation of the machine if the temperature of the rinse water falls below 180°F. The racks pass through the machine automatically on conveyor chains. The two-tank dishwashing machine should be timed so that the utensils are exposed to the machine sprays for not less than 40 seconds (20-second wash, 20-second rinse).

DESCALING DISHWASHERS

The accumulation of scale deposits in dishwashing machines should be prevented for at least two reasons. FIRST–excessive scale


DRIVE PAWL
SPEED SHIFT LEVER
UPPER RINSE SPRAY PIPES
FINAL RINSE TRIP LEVER
CONVEYOR DRIVE SHAFT
FINAL RINSE VALVE
LOWER FINAL RINSE SPRAY
CLUTCH ADJUSTING SCREWS
CLUTCH PLATE
FINAL RINSE THERMOMETER AND THERMOSTATIC INTERLOCK
STEAM INJECTOR
STEAM THERMOSTAT
STEAM INLET VALVE
FINAL RINSE STEAM AND WATER MIXING VALVE
SPEED REDUCTION GEAR
SUCTION STRAINER
OVERFLOW SKIMMER
TANK DRAIN VALVES
TANK DRAIN
SCRAP SCREENS
LOWER WASH SPRAY PIPES
CONVEYOR CHAIN ADJUSTMENT
CONVEYOR FOLLOWER SHAFT
SPLASH CURTAIN
HOT AND COLD WATER TANK FILL VALVES
WASH DISCHARGE LINE
RINSE AND WASH THERMOMETERS
RINSE DISCHARGE LINE

48.35

Figure 20-13.–Typical automatic double-tank dishwashing machine.

deposit on the inside of pipes and pumps will clog them and interfere with the efficient performance of the machine by reducing the volume of water that comes in contact with the utensils during the washing and sanitizing process. SECOND–scale deposits provide a haven for harmful bacteria.

The supplies needed for descaling are available through Navy supply channels. See the supply list below:

Stock Number	Description of Material
9G6810-00-264-6722	Orthophosphoric acid 85% technical, 7-lb bottle
9Q7930-00-282-9699	Detergent, general purpose 1-gal can
9Q7930-00-985-6911	Detergent, general purpose 5-gal pail

You should know the capacity of the dishwashing machine tanks. This may be determined by measuring (in inches) the inside dimensions of each tank and applying the following formula: length X width X depth (to water line) ÷ 231 = capacity in gallons.

Steps and key points in descaling the machine:

1. Fill the tanks halfway to the overflow level with hot, clean water. If tanks are not fitted with water level indicators, remove a section of the scrap tray in each tank so that you can see the overflow pipe.
2. Add the required amount of acid and detergent to the water to prepare the cleaning solution. Measure amounts carefully. Use 7 fluid ounces of orthophosphoric acid 85% plus 1/2 fluid ounce of detergent, general purpose, for each gallon capacity of the tank when filled to overflow level.
3. Complete filling the tanks. Fill to overflow level.
4. Put scrap screens, spray pipes, and splash curtains in place. Scale deposits on all attachments must be removed.
5. Turn on machine. Operate the machine at the highest possible temperature for 60 minutes.
6. Turn off and drain the machine. Open the drain valves and allow all the cleaning solution to drain from the tanks.
7. Refill. Use fresh hot water.
8. Turn on the machine. Operate the machine at the highest temperature for 5 minutes.

Repeat steps 7 and 8 several times. The entire method should be repeated at such intervals as may be required to assure efficient operation of the dishwashing machine.

LAUNDRY EQUIPMENT

Equipment used in the cleaning, drying, and pressing of clothing includes washers, extractors, dryers, dry-cleaning machines, and various types of presses.

Most of the maintenance associated with this equipment is concerned with inspecting and lubricating the various parts.

Most laundry equipment is equipped with a number of safety devices. If disabled, these safety devices can result, and have resulted, in shipboard fires, damage to equipment, damage to clothing, and in many cases personnel injuries. Special attention should be given these safety devices during preventive and corrective maintenance with extra special attention being given those devices designed to protect operators.

AUXILIARY BOILERS

Auxiliary boilers are used in diesel-driven ships to supply steam for distilling plants, space heating, oil heating, water heating, galley, and laundry. These boilers are equipped with all auxiliaries, accessories, and controls to effect a unit assembly and are arranged to operate as complete and self-contained steam generating plants. Because of this distinctive arrangement, these boilers are called by their manufacturers "steam generating units" and "steam generators."

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TYPES OF BOILERS

Auxiliary boilers in Navy ships may be divided into two groups: Water tube type boilers and fire tube type boilers. Boilers of the water tube type are further classified as natural-circulation boilers and forced-circulation boilers.

Water Tube Natural-Circulation Boilers

Water tube natural-circulation boilers consist basically of a steam drum and a water drum connected by a bank of generating tubes. The two drums are also connected by a row of water tubes which form a water-cooled sidewall opposite the tube bank. The water-wall tubes pass beneath the refractory furnace floor before they enter the water drum. The steam and water drums may also be connected by several larger tubes, called downcomers, located at the front and rear ends of the boiler. Refractory is used to protect these downcomers from contact with the combustion gases.

In operation the water in the tubes receives heat from the furnace gases, becomes less dense, and flows toward the upper end of the tubes. Before reaching the steam drum, some of the water forms steam bubbles which rise to the top of the steam drum. The hot water and steam are displaced by more of the relatively cool water flowing from the upper drum through the downcomers to the lower drum and into the tubes. Thus a continuous circulation is established.

Water Tube Forced-Circulation Boilers

Water tube forced-circulation boilers differ from the natural-circulation boilers chiefly in that pumps, instead of a difference in the density of ascending and descending fluids, force a continuous circulation of water through the system. In some auxiliary boilers of the forced-circulation type, water is circulated through coils which may be located above, or form a part of, the combustion space. The hot water from these coils is discharged into the chamber, where part of the water flashes into steam. The steam accumulates in the upper portion of the chamber and the unevaporated water collects in the lower portion. The water is recirculated back to the heating coil or water tank. (See chapter 221 of *NAVSHIPS' Technical Manual.*)

Fire Tube Boilers

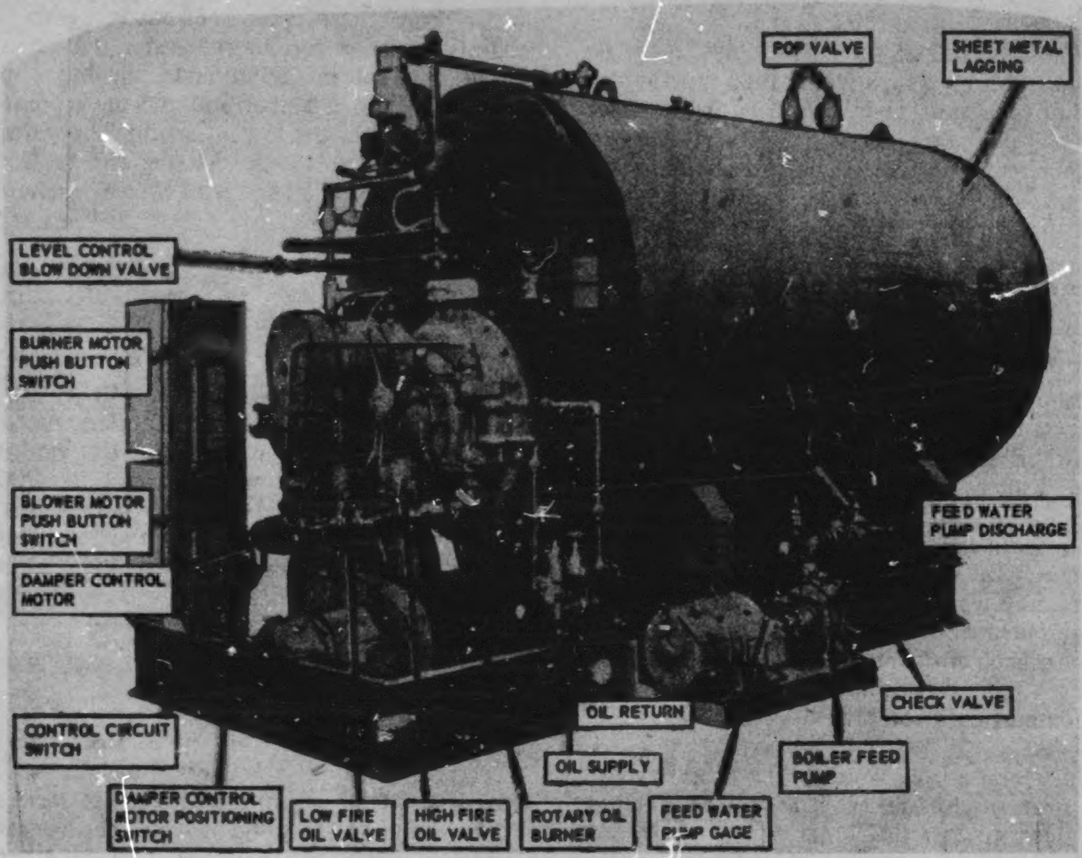
Fire tube type boilers are generally similar to Scotch marine or locomotive boilers. In this type of boiler the gases of combustion pass through tubes that are surrounded by water. There are a number of auxiliary boilers of the fire tube type in use in diesel-driven ships. Figure 20-14 illustrates a typical unit.

OIL BURNERS

Oil burners used on auxiliary boilers are of the mechanical atomizing type. Most burners have pressure type atomizers; however, a few atomizers of the rotary cup type are in use. Two of the types commonly used are the constant capacity pressure atomizing burner and the variable capacity pressure atomizing burner.

Constant Capacity Pressure Atomizing Burners

Constant capacity pressure atomizing burners are arranged for electric ignition and automatic control. Basically, these burners consist of a burner cone or plenum chamber connected to the fan casing, brackets for nozzle and electrodes, and an oil atomizing nozzle. Variation of boiler load with this type of burner is accomplished by the automatic "off and on" cycling of the burner. Burners intended to meet wide variation of boiler steaming loads are designed with dual or triple nozzle arrangements to eliminate excessive cycling. In such burners one nozzle is used as a pilot and additional


POP VALVE
SHEET METAL LAGGING
LEVEL CONTROL BLOW DOWN VALVE
BURNER MOTOR PUSH BUTTON SWITCH
BLOWER MOTOR PUSH BUTTON SWITCH
DAMPER CONTROL MOTOR
FEED WATER PUMP DISCHARGE
CHECK VALVE
OIL RETURN
CONTROL CIRCUIT SWITCH
OIL SUPPLY
BOILER FEED PUMP
DAMPER CONTROL MOTOR POSITIONING SWITCH
LOW FIRE OIL VALVE
HIGH FIRE OIL VALVE
ROTARY OIL BURNER
FEED WATER PUMP GAGE

75.298

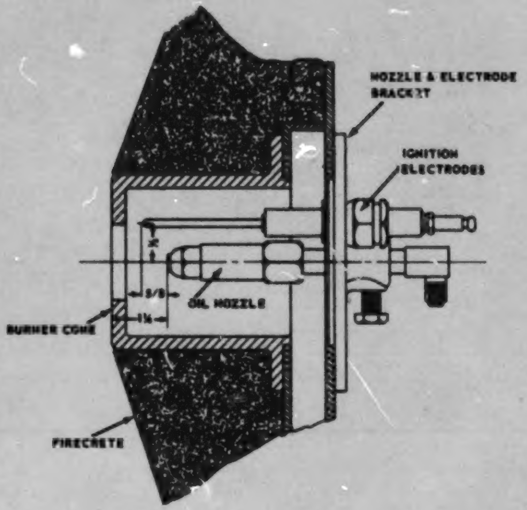
Figure 20-14.—Fire tube auxiliary boiler.

nozzles are manually cut in as required. Standard commercial nozzles are used with burners of this type.

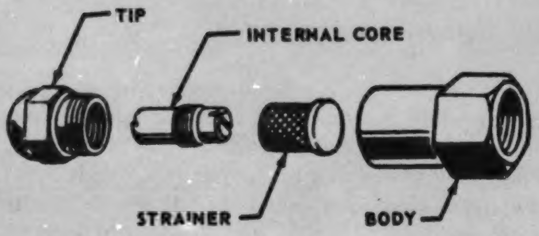
A typical arrangement of a burner and construction of the oil-atomizing nozzle are shown on figures 20-15 and 20-16 respectively.

Variable Capacity Pressure Atomizing Burner

The atomizing unit of a variable capacity pressure atomizing burner consists of a burner barrel, nozzle body or distributor sprayer plate, orifice plate, and atomizer nut. The capacity of these atomizers is regulated by an oil control valve placed in the oil return line. While the supply of oil to the atomizer is kept at a constant pressure necessary for proper atomization, amounts of oil returned from the atomizer may be varied by increasing or decreasing pressure at the oil control valve. The amount of oil atomized is always the difference between oil supplied to and oil returned from the atomizer. An oil metering valve is linked with a mechanism regulating air admission to the burner so that air and oil may be properly proportioned over the entire range of burner operation. Typical construction of this type of atomizer is illustrated in figure 20-17.



75.297
Figure 20-15.—Constant capacity pressure atomizing burner as installed in boiler front.



75.298
Figure 20-16.—Burner nozzle disassembled.

BOILER CONTROLS

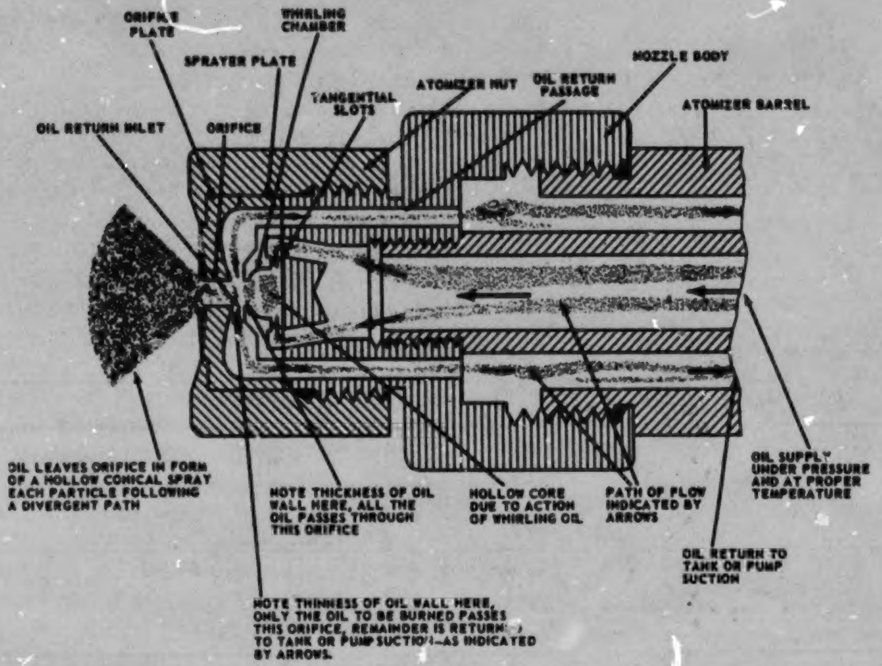
Methods of operating auxiliary boilers may be manual, semiautomatic or automatic. Controls installed on auxiliary boilers depend on the method of operation. Feedwater controls that are used may be classified as thermomechanical, float, or electrode type.

1. Thermomechanical Feedwater Regulators are used on water tube natural-circulation boilers. The control element depends on the water level in the boiler steam drum. Thus, a certain water level in the drum corresponds to a certain opening of the feedwater control valve.

2. Float Type Feedwater Regulating and Low Water Cutoff Controls are used on water tube and fire tube type boilers arranged for semiautomatic or automatic operation. These controls consist of a float chamber, a float, and a switch. The float chamber is connected to the boiler drum so that the water level in the chamber is always the same as the water level in the drum. The float is interlinked with a switch which is wired into the feed pump control circuit. The switch contacts are open when the water level in the drum and float chamber is normal. A drop in the water level closes the switch contacts. This starts the feed pump. When the water level is restored to a predetermined high position, the switch breaks the contact and stops the feed pump. The low water cutoff feature consists of an additional switch. This switch is mounted in the same case as the pump switch but wired into the burner circuit. If the water level drops below a permissible minimum, the low water cutoff switch breaks the burner circuit and stops the burner.

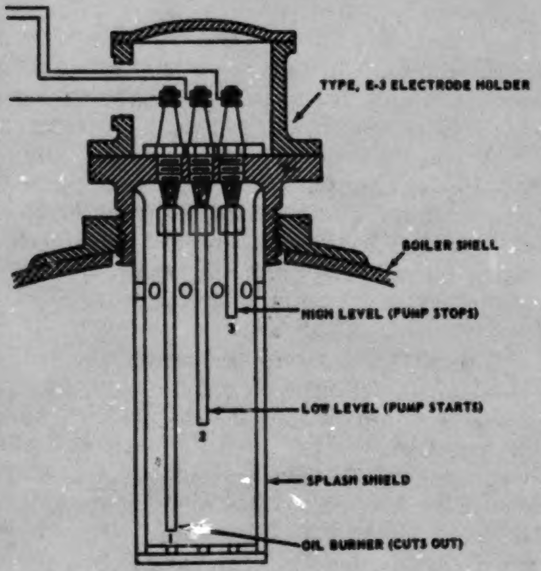
3. Electrode Type Feedwater Regulating and Low Water Cutoff Controls also are used on water tube and fire tube type boilers arranged for semiautomatic or automatic operation. These controls consist of an electrode assembly and a water level relay. The electrode assembly contains three electrodes of different lengths, corresponding to the high, low, and cutoff water levels in the boiler drum. A typical electrode assembly is illustrated in figure 20-18.

The electrode assembly is installed on the top of the boiler drum so that the normal water level is at approximately the midpoint between the high level and the low level electrodes. The electrodes are electrically wired to the water level relay assembly. The relay contains the feedwater pump START and STOP contacts which are wired to the feedwater pump controller and the low water cutoff which is wired into the burner circuit. The feed pump is


ORIFICE PLATE
WHIRLING CHAMBER
SPRAYER PLATE
TANGENTIAL SLOTS
ATOMIZER NUT
OIL RETURN PASSAGE
NOZZLE BODY
ATOMIZER BARREL
OIL RETURN INLET
ORIFICE
OIL LEAVES ORIFICE IN FORM OF A HOLLOW CONICAL SPRAY EACH PARTICLE FOLLOWING A DIVERGENT PATH
NOTE THICKNESS OF OIL WALL HERE, ALL THE OIL PASSES THROUGH THIS ORIFICE
HOLLOW CORE DUE TO ACTION OF WHIRLING OIL
PATH OF FLOW INDICATED BY ARROWS
OIL SUPPLY UNDER PRESSURE AND AT PROPER TEMPERATURE
OIL RETURN TO TANK OR PUMP SUCTION
NOTE THINNESS OF OIL WALL HERE, ONLY THE OIL TO BE BURNED PASSES THIS ORIFICE, REMAINDER IS RETURNED TO TANK OR PUMP SUCTION—AS INDICATED BY ARROWS.

38.75

Figure 20-17.—Variable capacity pressure atomizing burner, showing oil flow.


TYPE, E-3 ELECTRODE HOLDER
BOILER SHELL
HIGH LEVEL (PUMP STOPS)
3
LOW LEVEL (PUMP STARTS)
2
SPLASH SHIELD
1
OIL BURNER (CUTS OUT)

75.299

Figure 20-18.—Water level electrode assembly.

started when the water level in the boiler drops below the middle electrode. After the water level is restored and reaches the high level electrode, the feed pump is stopped. In the event the water level is not restored and drops below the longest electrode, the cutoff contacts of the water level relay stop the burner by breaking the burner circuit.

4. Limit Pressure Switches and Pressuretrols are operated by steam pressure and control burner operation within a fixed range of boiler pressures. Basically, they consist of a bellows assembly linked with a snap switch through a pressure adjusting mechanism. The bellows assembly expands or contracts with any increase or decrease in boiler pressure and causes the snap switch to open or close its contacts. The pressure adjusting mechanism is set so that the contacts open and close at definite cutout and cut-in boiler pressures. The differential between the cutout and cut-in pressures may be either adjustable or fixed.

On boilers adjusted for automatic operation, the snap switch is wired into the burner electric circuit so that it will break the circuit and stop the burner when the cutoff pressure is reached and will make the circuit and restart the burner when the boiler pressure falls below the cut-in pressure.

On boilers arranged for semiautomatic operation (manual ignition), the snap switch is wired into the burner circuit in such a way that it will break the circuit at the cutoff pressure and will hold it open, preventing manual restart of the burner, until pressure falls below the cut-in setting.

A typical pressure switch arrangement is shown in figure 20-19.

5. Modulating Pressuretrols are steam-operated rheostat switches used for automatic regulation of oil and air admission to the burners. These switches are similar in design to limit pressuretrols, except that they are equipped with a potentiometer coil. The switch is wired into the circuit of a reversing type motor which operates the linkage of the air-oil ratio adjusting mechanism. When boiler pressure increases or decreases with variation of the boiler load, the bellows assembly of the switch expands or contracts, causing a sliding contact to move across the potentiometer coil. The change in electrical balance of the motor circuit causes the motor to rotate. The movement of the motor, transmitted by a crank arm to the linkage between the fuel metering valve and the damper air vanes, resets the oil metering valve and the damper to positions corresponding to the firing rate required by the boiler load.

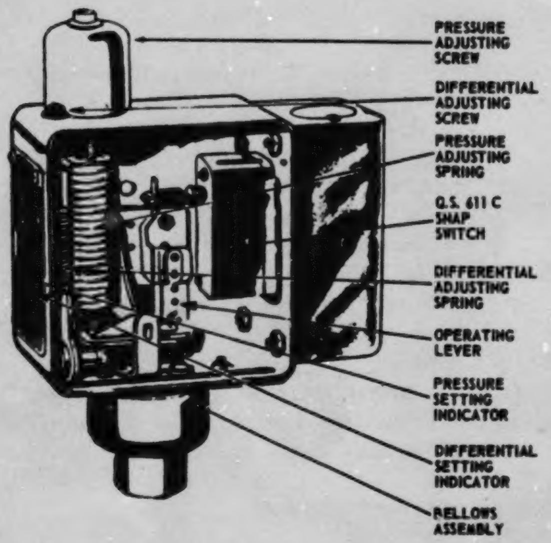
SAFETY COMBUSTION CONTROLS

Safety combustion controls are designed to shut down the burner to prevent flooding the furnace with oil after initial ignition, in the event of ignition failure or flame failure. These controls are either a thermostatic type (stack switches and pyrostats) or a photoelectric type.

Stack Switches and Pyrostats

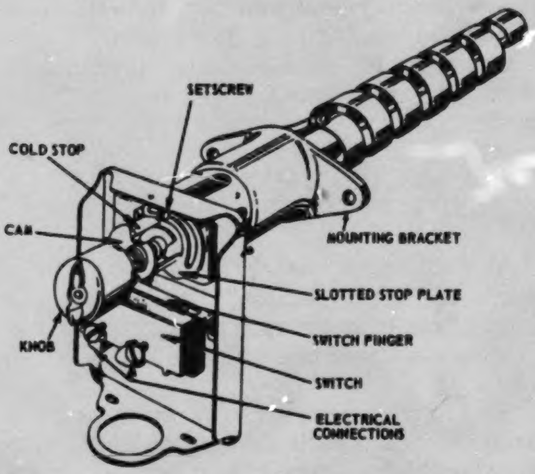
Stack switches and pyrostats basically consist of a bimetallic helix, a mounting frame, a shaft carrying a contact mechanism, and an electric switch. The helix is connected to the mounting frame at one end and to the shaft at the other.

Typical construction of a pyrostat is shown in figure 20-20.


PRESSURE ADJUSTING SCREW
DIFFERENTIAL ADJUSTING SCREW
PRESSURE ADJUSTING SPRING
Q.S. 611 C SNAP SWITCH
DIFFERENTIAL ADJUSTING SPRING
OPERATING LEVER
PRESSURE SETTING INDICATOR
DIFFERENTIAL SETTING INDICATOR
BELLOWS ASSEMBLY

75.300

Figure 20-19.–Pressure switch.


SETSCREW
COLD STOP
CAM
MOUNTING BRACKET
SLOTTED STOP PLATE
KNOB
SWITCH FINGER
SWITCH
ELECTRICAL CONNECTIONS

75.301

Figure 20-20.–Construction details of a pyrostat.

The stack switches and pyrostats are mounted on the boiler smoke pipe or hood, with the helix protruding into the path of the combustion gases. The switch is wired into the burner electric circuit so that when the contacts are open, no current is supplied to the burner except through the Protectorelay (to permit initial ignition). When there is no heat in the boiler, the switch contacts are open. When the burner is ignited, the increase in the stack temperature causes the helix to expand, and this expansion in turn causes the shaft to rotate and close the contacts. Unless the stack temperature decreases, the contacts will remain closed, permitting the operation of the burner. In the event of flame failure, the helix contracts as the stack temperature falls and causes the shaft to rotate in the reverse direction. This opens the contacts and shuts down the burner.

Photoelectric Safety Combustion Controls

Photoelectric safety combustion controls consist basically of a photoelectric cell, an amplifying unit, and a relay. These controls operate by the luminosity (light) of the flame acting upon the photoelectric cell. The photoelectric cell makes a contact within itself when light rays impinge upon it. The amplified current of the photoelectric cell operates the relay, which is wired into the burner control circuit, causing the relay to close the burner circuit when the flame is established and to break the burner circuit in the event of flame failure.

OPERATION AND MAINTENANCE OF AUXILIARY BOILERS

The wide variations in design of auxiliary boilers and their auxiliaries, accessories, and controls make it impractical to give general operating and maintenance instructions for all types in use.

Personnel charged with the operation of an auxiliary boiler should be thoroughly familiar with the boiler, its controls, and all safety precautions. Operating instructions can be found in the appropriate manufacturer's technical manual. Maintenance requirements are given in your ship's Planned Maintenance System Manual.

TESTING BOILER WATER

You must be able to determine the actual condition of boiler water. This can only be accomplished through tests of the boiler water. The tests that you may be required to perform include chloride tests, alkalinity tests, and hardness tests. The results of these tests are reported in terms of EQUIVALENTS PER MILLION (epm). (Refer to chapter 17 of this training manual for definitions of units used to report results of tests.)

Making boiler water tests is a rather complicated job which requires a great deal of care and attention on your part. A water test result that is based on careless or inaccurate test procedure is not only useless but also may be actually dangerously misleading. You will not be able to obtain any useful information about the condition of the boiler water unless you perform each test with real precision and accuracy. Some of the things you will need to be particularly careful about when making boiler water tests are:

1. Getting proper samples of boiler water.
2. Using the correct chemicals for each test.
3. Measuring chemicals accurately.
4. Making all measurements and readings as accurately as possible.
5. Interpreting test results correctly.
6. Keeping all test equipment clean and in good condition.

Boiler water testing is not a skill you can learn merely by reading about the subject. In addition to studying the information given in this chapter, you should take every opportunity to get actual practice in making the tests. Detailed information on boiler water testing is given in Chapter 220 (9560) *NAVSHIPS' Technical Manual.*

Sampling Boiler Water

Samples of boiler water taken for analysis must be truly representative of the water in the boiler. The container into which the sample is drawn must be clean, and the sampling connection must be thoroughly flushed out to remove any sediment and stagnant water that may be trapped in the line or in the connection.

The water sample must be protected from contamination during the interval between sampling and analysis. It should not be exposed to air for any long period of time because an alkaline sample will absorb carbon dioxide from the air, resulting in a false low reading for alkalinity.

Boiler water samples should be cooled down to below 100°F (37.7°C) before being tested. If a sample is not cooled, as much as one-third of the sample might flash into steam and be lost—if such a sample is tested, the results will not reflect the true condition of the water in the boiler.

Boiler Water Testing Equipment

All the equipment required for making hardness, chloride, and alkalinity tests of boiler water is assembled in a standard boiler water testing cabinet (fig. 20-21).

Each chemical used in making boiler water tests must be prepared and used in strict accordance with NAVSEA instructions. Some of

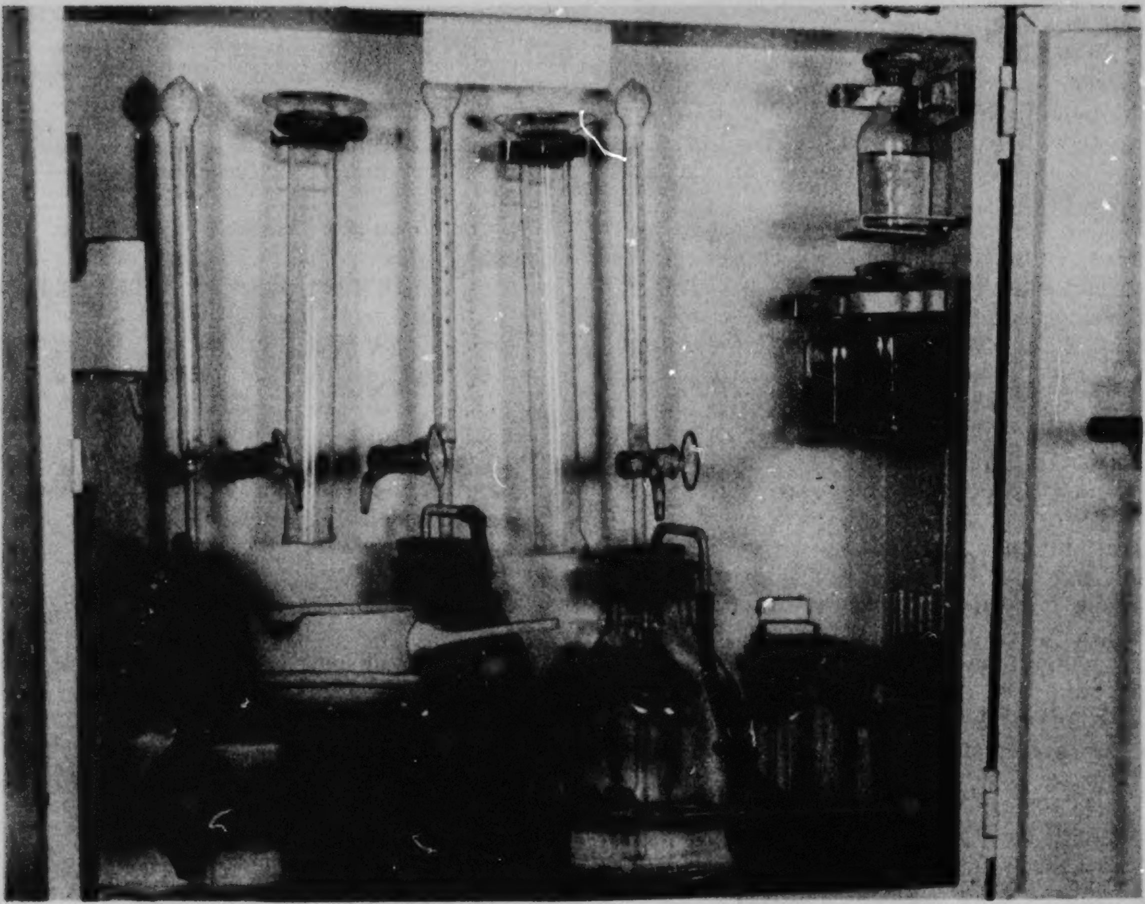


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Figure 20-21.—Boiler water testing cabinet.

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the chemicals are supplied in ready-to-use form. Others are supplied in solution form but must be diluted before they are used. Detailed instructions for preparing and using the chemicals needed for boiler water tests are given in Chapter 220 (9560) *NAVSHIPS' Technical Manual.*

When using the chemicals required for making boiler water tests, be sure to observe all appropriate safety precautions. Some of the chemicals are very dangerous if they are not handled correctly.

Before starting to use the boiler water testing equipment, be sure you understand how to use it. You may have some difficulty because of the way this equipment is calibrated. Most of the bottles, burettes, cylinders, and other items are calibrated in a metric system unit called milliliters (abbreviated ml). One milliliter is 1/1000 of a liter. A liter is equal to approximately one quart. Until you become thoroughly familiar with the calibration of the equipment, you will have to be particularly careful in making measurements and in taking readings.

The boiler water testing cabinet contains three 1-liter (1000-milliliter) bottles for the chemicals used in making the tests for alkalinity, hardness, and chloride. One bottle is for nitric acid, one is for mercuric nitrate, and the third is for soap solution. A 10-ml, automatic-zero burette and an aspirator bulb for filling the burette are fitted into the stopper of each bottle. To fill the burette, you merely press the aspirator bulb and then release it. When properly filled, the burette will drain down to the ZERO mark automatically. You must start all tests by filling the burettes and then draining them down to the zero mark. The burette tip must always be completely filled with the chemical solution.

A liquid in a burette has a slightly curved surface. This curved surface is called a MENISCUS. When reading a burette, always take the reading from the BOTTOM of the meniscus.

Handle all boiler water testing equipment carefully so that it will not become damaged. Keep the equipment absolutely clean at all times. If it is not clean when it is used, the tests will not be accurate. Clean the soap solution burette with distilled water or with alcohol. Rinse the dishes, pipettes, and graduated cylinders with distilled water and wipe immediately after each use. You may use soap if necessary to wash this equipment, but you must entirely remove the soap by very thorough rinsing. NEVER use lye, scouring powder, or any stronger cleanser to clean chemical glassware and porcelain. If soap and water will not clean the equipment properly, use a weak acid solution; but be sure to rinse all the acid off.

The burette stopcocks must be lubricated occasionally. A special stopcock lubricant is provided in the boiler water testing cabinet.

When using the water testing equipment, do not exert pressure on the burette tip. Do not attempt to remove a burette or a bulb from a stopper except when it is necessary to replace a broken burette.

Testing for Alkalinity

Alkalinity is a property that water acquires from certain impurities. The allowable limits for alkalinity authorized by NAVSEA are 2.5 to 3.5 epm.

There are two methods of testing for alkalinity. The phenolphthalein test is used for testing water from steaming boilers and for testing water from idle boilers which have been steamed. The methyl-purple test is used for testing water from freshly filled boilers which have NOT been steamed. If a boiler has been idle for a long time, it is best to use both tests.

PHENOLPHTHALEIN TEST.—The phenolphthalein test for alkalinity is performed as follows:

1. Fill the nitric acid burette and allow it to drain down to zero. Be sure the tip of the burette is full and completely free of air bubbles. Place a container of some sort under the burette tip to catch the drop or two of nitric acid that will drip from the tip as you are filling it. It is all right to use a casserole for this purpose, but you must be sure to clean it thoroughly before using it for the test.
2. Take a sample of boiler water.
3. Rinse a 100-ml graduated cylinder with some of the sample water. Then fill the cylinder to the 50-ml mark.

4. Pour the 50-ml sample from the graduated cylinder into a CLEAN casserole.

5. Add two or three drops of phenolphthalein indicator. If the sample is alkaline, the water will turn a DEEP PINK color.

6. Add nitric acid from the burette to the sample, while stirring the sample continuously. Add only one drop of acid at a time. The pink color will begin to fade and will presently disappear.

7. As the pink color just disappears, read the burette, taking the reading from the bottom of the meniscus. The burette reading in milliliters equals the alkalinity of the sample in equivalents per million. For example, if the burette reads 2.9 milliliters, the sample has an alkalinity of 2.9 epm.

METHYL-PURPLE TEST.–The methyl-purple test for alkalinity is performed as follows:

1. Measure 50 milliliters of sample water into a clean porcelain casserole.

2. Add two drops of methyl-purple indicator. If the sample is alkaline, the water will turn GREEN.

3. Stirring the sample, add nitric acid solution a drop at a time until the color changes to purple. A gray tint precedes the purple end point color and gives warning of its approach.

4. As the color of the sample changes to purple, read the burette. The burette reading is numerically EQUAL to the alkalinity of the sample in epm.

The color change from green to purple is quite easily seen in clear water, but is not so easily seen in water that contains suspended iron compounds. The water for the test should, of course, be as free of suspended matter as possible. If it is not possible to obtain a sample that is clear enough for the methyl-purple test, you can obtain an approximate value for the alkalinity of the water in an unsteamed boiler by making a phenolphthalein test and multiplying the result by two.

Testing for Hardness

Water in which soap does not readily form a lather is said to be hard. Hardness is a property that water acquires from certain dissolved salts.

The procedure for testing boiler water for hardness is as follows:

1. Use the 100-ml graduated cylinder to transfer 50 ml of the sample water to the square 8-ounce bottle.

2. Fill the soap solution burette and allow it to drain down to zero. Be sure the burette tip is full.

3. Add 0.4 ml of soap solution to the sample. This amount of soap solution is called the LATHER FACTOR because it is the amount of soap solution required to produce a lather that will persist for 5 minutes over the entire surface of a 50-ml sample of pure water. (Until recently, the lather factor had to be determined for each new lot of soap solution. However, the lather factor appears to be very close to 0.4 ml for all soap solutions used in the hardness test, so the lather factor is now assumed to be 0.4 ml.)

4. Stopper the bottle and shake it vigorously.

5. Lay the bottle on its side and start a stopwatch. If the lather persists for 5 minutes over the entire surface of the water, report ZERO HARDNESS.

6. If the latter does not persist for 5 minutes over the entire surface of the water, some hardness is present. Add more soap solution in 0.1 ml increments, stopper the bottle, shake it, lay it on its side, and start the stopwatch. Repeat this procedure as often as necessary to obtain a lather that persists for 5 minutes and completely covers the surface of the water sample.

7. Read the burette, taking the reading from the bottom of the meniscus.

8. Calculate the hardness. Subtract the lather factor (0.4 ml) from the burette reading and multiply the result by 0.2 to obtain the hardness of the sample. For example, if the

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reading on the burette is 0.7 ml, the hardness of the sample is calculated as follows:

$$(0.7 - 0.4) \times 0.2 = 0.06$$

Therefore, the hardness of the sample is 0.06 epm.

Testing for Chloride Content

The term "chloride content" really refers to the concentration of the chloride ion, rather than the concentration of any one sea salt. Because the concentration of chloride ions is relatively constant in seawater, the chloride contents may be used as a measure of the amount of solid matter that is derived through seawater contamination. The results of the chloride tests are used as one indication of the need for blowdown.

Until recently, the chloride indicator used in making the chloride test was furnished in solution form, ready to use. This solution deteriorated after being stored for some time, particularly if it was stored in a hot place. To prevent this deterioration, chloride indicator is now supplied dry in capsule form so that it can be made up into solutions as it is needed.

To make up a chloride indicator solution, empty the contents of one capsule of the dry indicator into 50 milliliters of a specified type of alcohol and dissolve. The resulting solution is identical with the solution previously furnished for shipboard use, and it is used in exactly the same way.

The chloride indicator solution prepared from the capsules is also subject to deterioration from prolonged storage and should be made up in small batches. It should not be used after it has been kept in solution form for more than 9 months. It must not be stored for prolonged periods in hot locations.

The procedure for making the chloride test is as follows:

1. Rinse a 100-ml graduated cylinder with some of the sample water, and then measure 25 ml of the sample in the graduated cylinder.
2. Pour the 25-ml sample into a clean casserole.
3. Add five drops of chloride indicator to the sample in the casserole. The water will turn BLUE-VIOLET or RED, depending on how alkaline it is.
4. Fill the nitric acid burette and allow it to drain down to zero. Be sure the tip of the burette is full.
5. Add nitric acid to the sample, one drop at a time, stirring continuously, until the blue-violet or red color just disappears. The water will probably be pale yellow.
6. Add exactly 1.0 ml more nitric acid.
7. Fill the mercuric nitrate burette and allow it to drain down to zero. Be sure the burette tip is full.
8. Add mercuric nitrate from the burette, stirring continuously, until the pale yellow color disappears and a pale blue-violet color persists throughout the sample. The blue-violet color indicates the end point of the test. Add the mercuric nitrate fairly rapidly at first, but add it very slowly—drop by drop—as the end point is approached.
9. Read the burette, taking the reading from the bottom of the meniscus. The burette reading in milliliters equals the chloride content of the sample in equivalents per million. For example, if the reading on the burette is 1.3 milliliters, the sample of boiler water has a chloride content of 1.3 epm.

FIREFIGHTING EQUIPMENT

Information on the fire hazards which exist aboard ship and on much of the equipment used in fighting fires and the control of damage has been presented in *Basic Military Requirements*, NavPers 10054-D, and in *Fireman*, NavPers 10520-E. The information on firefighting equipment presented in this manual deals primarily with engine-driven equipment.

ENGINE-DRIVEN FIRE PUMPS

Fire pumps are usually the horizontal single-stage, centrifugal type, with double-suction impellers. Fire pumps are generally driven by either an electric motor or a steam turbine; emergency fire pumps, however, are usually driven by diesel engines, and some portable pumps used in firefighting are driven by gasoline engines.

The gasoline engine-driven portable pump used aboard ship is the P-250. The capacity and limitation are given in the Navy Training Manuals mentioned earlier in this section. The capacities of pumps driven by diesel engines may be from 100 to 250 gpm in small ships and up to 2,000 gpm in large ships.

Instructions for the operation of all pumps cannot be covered in this manual because of the great number of different makes, types, and designs in use in naval service. Manufacturers' technical manuals are furnished with most engine-driven pumps. These technical manuals contain detailed information concerning operation, maintenance, and repair. You should study the appropriate technical manual carefully before attempting to operate a particular pump installation.

The procedures for the operation, maintenance, and repair of the gasoline engine-driven portable pumps previously mentioned in this chapter are similar. The pump selected as a representative type for the purpose of discussion in this training manual is the P-250.

OPERATION OF THE P-250 PUMP

Engine-driven fire pumps are furnished on practically every ship in the Navy. In the battle and disaster bills of a ship, Enginemen are commonly assigned as operators of the engine-driven pumps. Operating procedures for the P-250 pump are described in this section.

Starting the P-250 Pump

Before attempting to start the P-250 be sure that the suction hose connections between the water and the pump are tight and that the strainer (or eductor when used) is completely submerged in the water. Use gaskets of the proper size at the suction connection to the pump and in all hose connections. If the pump fails to take suction or if the discharge at the nozzle shows an uneven stream, air is probably leaking through a poor connection into the suction side of the pump. Be sure the screen to the suction hose rests in clear water; if the screen rests in mud or debris, these are likely to be drawn into the pump. Be sure to support the suction hose by a line so that the pump casing does not bear the weight of the hose. Also make sure that the suction hose does not, at any point, rise above the level of the pump inlet; raising the hose above the inlet tends to form an air pocket which interferes with proper priming. Do not run the pump in a confined space unless an exhaust hose is connected to carry toxic, engine-exhaust gases out of the space. With these inspections complete, proceed as follows:

1. Fill the fuel tank with the proper mixture of gasoline and oil. To each gallon of gasoline add 1/2 pint of Navy symbol 3065 (SAE-30). Since this is the only lubrication the pump receives, shake the tank vigorously until the oil and gasoline are thoroughly mixed. The capacity of the tank is approximately 6 gallons.

2. Clamp the tank to the top of the frame with the spring clamps provided.

3. Connect the fuel hose assembly from the fuel tank to the plug provided on the control panel.

4. When the unit has been assembled, pump fuel to the carburetor by pressing the push button on the tank until you feel a resistance. Do not pump after the resistance is felt because you could damage the pump diaphragm.

5. Place the water outlet valve in the closed position and make certain the hand priming filler cap is closed.

6. Pull the choke knob, located on the control panel, to the extended position.

7. Set the high and low speed knob on the control panel 3/4 of a turn from the closed position.

8. Pull the starting rope rapidly. Do not jerk the rope. After the engine starts and runs for a few seconds, push the choke knob in. The starter cord will automatically rewind.

9. Check the pressure gage to be sure water pressure is building up. Since the pump is self-priming, pressure should build up approximately 20 seconds after the engine is started. Do not run the engine more than 45 seconds unless pressure shows on the gage, as the engine may overheat. If no pressure shows, stop

the engine, retighten all suction connections, and try priming again.

10. When pressure shows on the gage, slowly open the outlet valve to the discharge hose.

11. Adjust the carburetor high-speed dial to the best running position. To make the slow speed adjustment, slow the engine with the throttle stop button, then set the slow-speed dial to the best position.

12. During pump operation, check the water pressure to ensure it is at the desired pressure.

13. Make sure the pump is not operated more than 15 to 20 seconds with the discharge valve closed. If the pump is operated in a closed compartment, make sure the exhaust hose is tight and no leakage occurs.

Stopping and Restarting the P-250 Pump

To stop the P-250 pump, press the stop button on the control panel and keep it depressed until the engine is completely stopped.

To restart the engine when it is still warm, it is necessary only to pull the starter cord. NO choking should be necessary. If the engine does not start immediately, you may use the choke, but be careful to avoid flooding the engine.

Care and Maintenance

After the pump has been operated and shut down, always prepare it for temporary storage as follows:

1. Release the tank pressure by loosening the filler cap. Retighten the cap. Remove the fuel tank from the frame and disconnect the hose from the pump.

2. Disconnect the suction, exhaust, discharge and drain hose.

3. Drain the pump and power head by turning the entire unit so that the flywheel end is up. Tilt the unit back and forth until all the water is drained. Repeat several times, each time returning the unit to its normal position for a few seconds.

4. Flush the unit by pouring clean water into the impeller housing through the manual priming bowl. Drain the pump in the manner stated earlier.

5. Replace all thread protectors; clean and dry the unit.

To keep the unit in proper working order, set up and operate it once each week, with maintenance performed in accordance with the planned maintenance and the manufacturer's technical manual.

FIREMAIN SYSTEM AND ISOLATION VALVES

As a Fireman, you were introduced to the firemain systems used in Navy ships. As an Engineman, you will be required to know the location of the principal isolation valves of the firemain system in the engineering spaces and adjacent spaces on your ship. The location of the valves used to isolate sections of the firemain varies from one ship to another. In general, isolation valves are located in the mainstream in the fire main, in the risers, and in horizontal leads. In learning the location of isolation valves in your ship, study the piping diagram of the firemain system. Make a sketch of the system, noting particularly the location of each valve.

To avoid confusion and to eliminate the possibility of error when sections of the firemain are being isolated, all important valves in the firemain system are marked with identification numbers. If all engineering personnel know both the location and the identification number of each valve, an order to close or open a particular valve can be given without time being taken to describe the valve's location.

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CHAPTER 21

LATHES AND LATHE MACHINING OPERATIONS

Although machine shop work is generally done by men in other ratings, there may be times when you will find the lathe essential to complete a repair job. There are a number of different types of lathes installed in the machine shops in various Navy ships, including the engine lathe, horizontal turret lathe, vertical turret lathe, and several variations of the basic engine lathe, such as bench, toolroom, and gap lathes. All lathes, except the vertical turret type, have one thing in common in that for all usual machining operations the workpiece is held and rotated about a horizontal axis, while being formed to size and shape by a cutting tool. In the vertical turret lathe, the workpiece is rotated about a vertical axis. Of the various types of lathes, the type you are most likely to use is the engine lathe; therefore, this chapter deals only with lathes of that type and the machining operations you may be required to perform.

ENGINE LATHE

An engine lathe similar to the one shown in figure 21-1 is found in every machine shop, however small. It is used principally for turning, boring, facing, and screw cutting, but it may also be used for drilling, reaming, knurling, grinding, spinning, and spring winding. The work held in the engine lathe can be revolved at any one of a number of different speeds, and the cutting tool can be accurately controlled by hand or power for longitudinal feed and crossfeed. (Longitudinal feed is the movement of the cutting tool parallel to the axis of the lathe; crossfeed is the movement of the cutting tool perpendicular to the axis of the lathe.)

Lathe size is determined by two measurements: (1) the diameter of work it will swing over the bed and (2) the length of the bed. For example, a 14-inch X 6-foot lathe will swing work up to 14 inches in diameter and has a bed that is 6 feet long.

Engine lathes vary in size from small bench lathes that have a swing of 9 inches to very large lathes for turning work of large diameter such as low-pressure turbine rotors. The 16-inch lathe is the average size for general purposes and is the size usually installed in ships that have only one lathe.

PRINCIPAL PARTS

To learn the operation of a lathe, you must be familiar with the names and functions of the principal parts. Lathes from different manufacturers differ somewhat in construction, but all are built to perform the same general functions. As you read the description of each part, find its location on the lathe in figure 21-1 and the figures which follow. (For specific details of the features of construction and operating techniques, refer to the manufacturer's technical manual for the machine which you are using.)

Bed and Ways

The bed is the base or foundation of the working parts of the lathe. The main features of the bed are the ways which are formed on its

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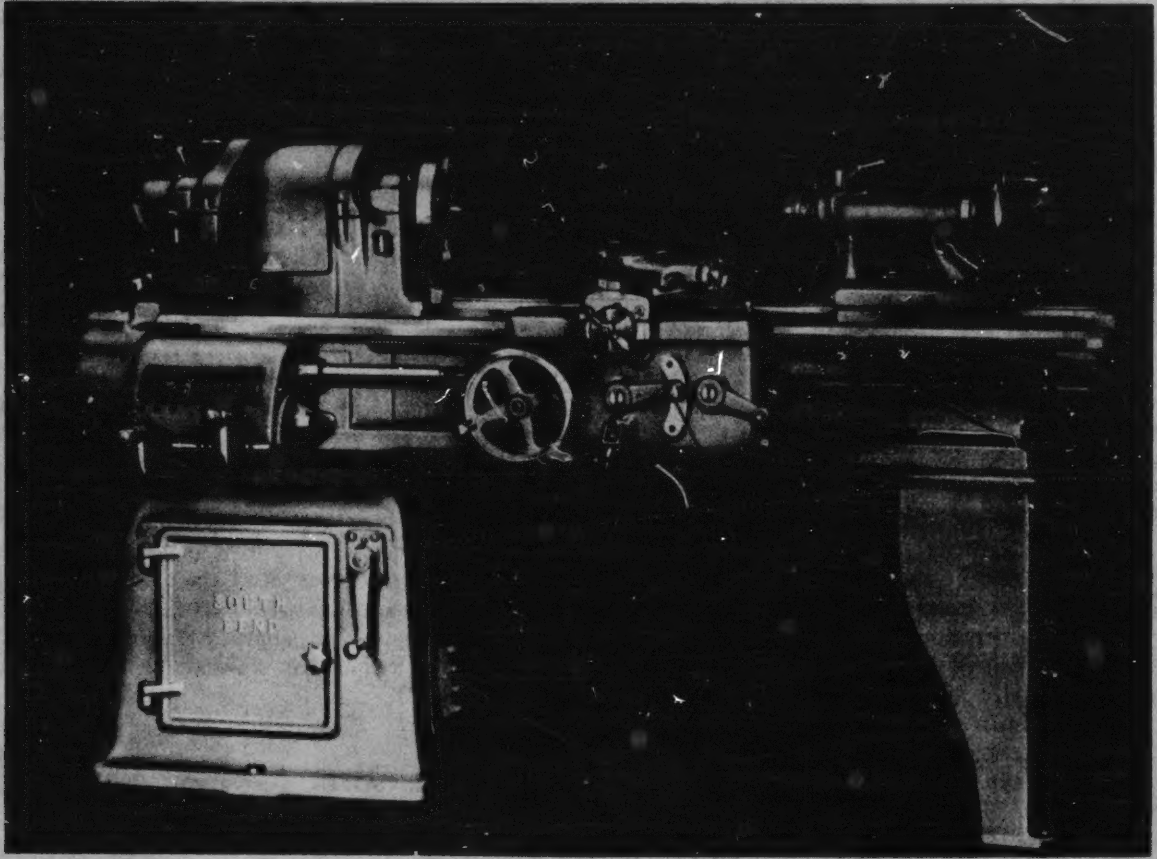

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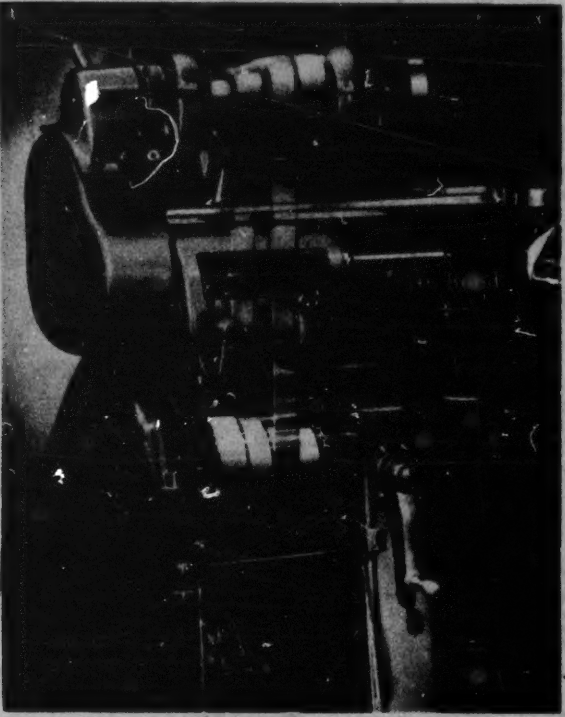
Figure 21-1.—An engine lathe.

upper surface and run the full length of the bed. The ways maintain the tailstock and carriage, which slide on them, in alignment with the headstock, which is permanently secured by bolts at one end (at operator's left).

Headstock

The headstock carries the headstock spindle and the mechanism for driving it. In the belt-driven type, shown in figure 21-2, the driving mechanism consists merely of a cone pulley that drives the spindle either direct or through back gears. When driving direct, the spindle revolves with the cone pulley; when driving through the back gears, the spindle revolves more slowly than the cone pulley, which, in this case, turns freely on the spindle. Thus two speeds are obtainable with each position of the belt on the cone; if the cone pulley has four steps as illustrated, eight spindle speeds can be obtained.

The geared headstock shown in figure 21-3 is more complicated but more convenient to operate, because speed changes are accomplished by merely shifting gears. It is similar to an automatic transmission except that it has more



78.71X
Figure 21-2.—Belt-driven type headstock.

gear-shift combinations and therefore a greater number of speed changes. A speed index plate attached to the headstock indicates the lever positions for obtaining the different spindle speeds.

Tailstock

The primary purpose of the tailstock is to hold the DEAD center to support one end of the work being machined on centers. However, the tailstock can also be used to hold tapered shank drills, reamers, and drill chucks. It is movable on the ways along the length of the bed to accommodate work of varying lengths and can be clamped in the desired position by the tailstock clamping nut. The tailstock can be adjusted laterally to cut a taper by loosening the clamping screws at the bottom of the tailstock. (See fig. 21-1.)

Before inserting a dead center, drill, or reamer, carefully clean the tapered shank and wipe out the tapered hole of the spindle. When holding drills or reamers in the tapered hole of a spindle, be sure they are tight enough so they will not revolve. If allowed to revolve, they will score the tapered hole and destroy its accuracy.

Carriage

The function of the carriage is to carry the compound rest, which in turn carries the cutting tool in the tool post. Figure 21-4 shows how the carriage travels along the bed over which it slides on the outboard ways.

The carriage has T-slots or tapped holes for clamping work for boring or milling. When used in this manner the carriage movement feeds the work to the cutting tool, which is revolved by the headstock spindle.

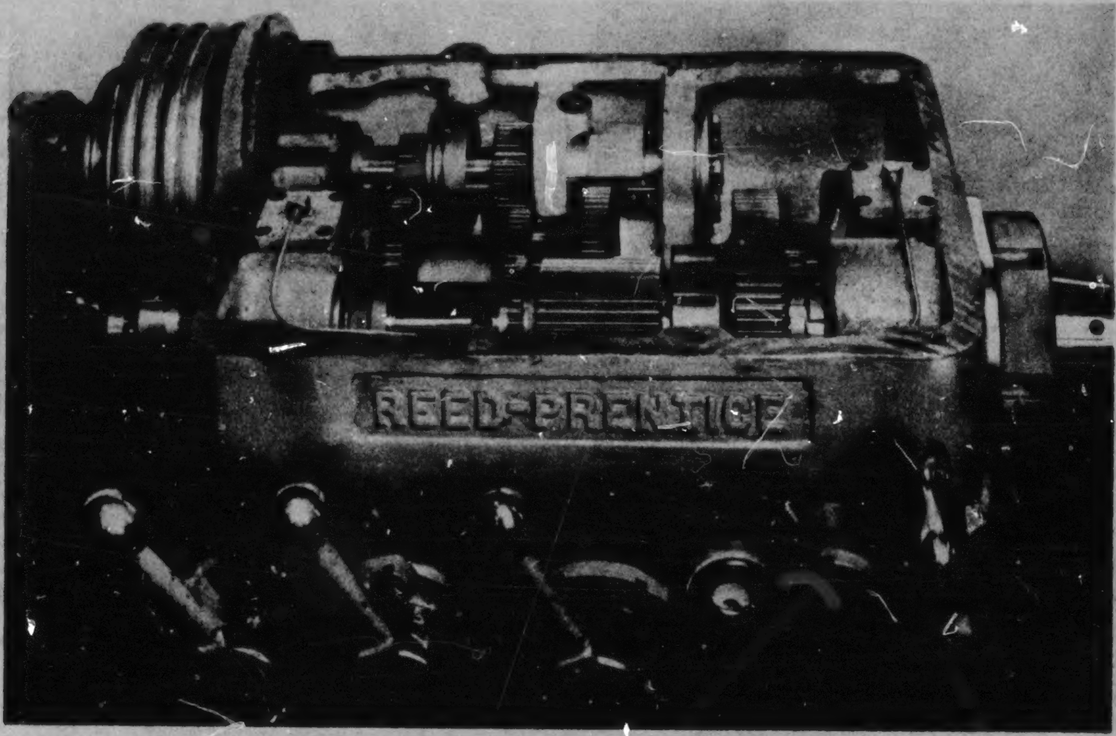
You can lock the carriage in any position on the bed by tightening the carriage clamp screw. This is done only when you do such work as facing or cutting-off, for which longitudinal feed is not required. Normally the carriage clamp should be kept in the released position. Always move the carriage by hand to be sure it is free before applying the automatic feed.

Apron

The apron is attached to the front of the carriage and contains the mechanism for controlling the movement of the carriage for longitudinal feed and thread cutting and the lateral movement of the cross-slide.

Feed Rod

The feed rod transmits power to the apron to drive the longitudinal feed and crossfeed



78.72X

Figure 21-3.—Sliding gear type headstock.

mechanisms. The feed rod is driven by the spindle through a train of gears, and the ratio of its speed to that of the spindle can be varied by means of change gears to produce various rates of feed. The rotating feed rod drives gears in the apron; these gears in turn drive the longitudinal feed and crossfeed mechanisms through friction clutches.

Some lathes do not have a separate feed rod, but in such lathes a spline in the lead screw serves the same purpose.

Lead Screw

The lead screw is used for thread cutting. Along its length, it has accurately cut Acme threads which engage the threads of the half-nuts in the apron when the half-nuts are clamped over it. When the lead screw turns in the closed half-nuts, the carriage moves along the ways a distance equal to the lead of the thread in each revolution of the lead screw. Since the lead screw is driven by the spindle through a gear train which connects them, the rotation of the lead screw bears a direct relation to the rotation of the spindle. Therefore, when the half-nuts are engaged, the longitudinal movement of the carriage is controlled directly by the spindle rotation and, consequently, the cutting tool is moved a definite distance along the work for each revolution that it makes.

Compound Rest

The compound rest provides a rigid adjustable mounting for the cutting tool. The

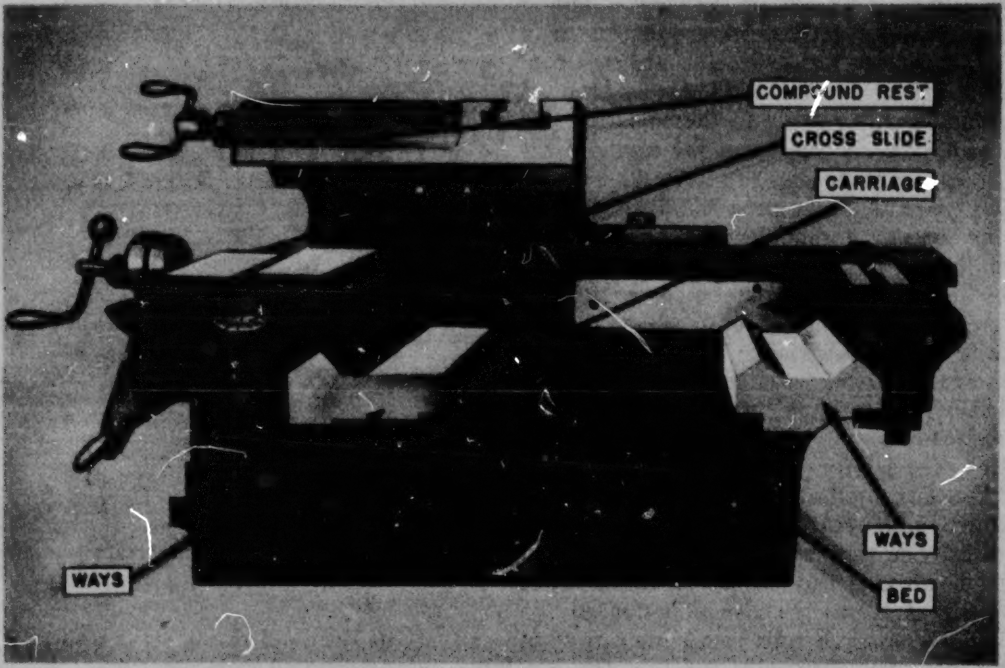


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Figure 21-4.–Side view of a carriage mounted on bed.

compound rest assembly has the following principal parts:

1. The compound rest SWIVEL can be swung around to any desired angle and clamped in position. It is graduated over an arc of 90° on each side of its center position for easier setting to the angle selected. This feature is used for machining short, steep tapers such as the angle on bevel gears, valve disks, and lathe centers.

2. The compound rest TOP, or TOP SLIDE, is mounted on the swivel section of a dovetailed slide. It is moved by the compound rest feed screw.

This arrangement permits feeding at any angle (determined by the angular setting of the swivel section), while the cross-slide feed provides only for feeding at right angles to the axis of the lathe. The graduated collars on the crossfeed and compound rest feed screws read in thousandths of an inch for fine adjustment in regulating the depth of cut.

Attachment and Accessories

Accessories are the tools and equipment used in routine lathe machining operations. Attachments are special fixtures which may be secured to the lathe to extend the versatility of the lathe to include taper cutting, milling, and grinding. Some of the common accessories and attachments used on lathes are described in the following paragraphs.

TOOL POST.–The sole purpose of the tool post is to provide a rigid support for the tool. It is mounted in the T-slot of the compound rest stop. A forged tool or a toolholder is inserted in the slot in the tool post. By tightening a setscrew, you will firmly clamp the whole unit in place with the tool in the desired position.

TOOLHOLDERS.—Some of the common toolholders used in lathe work are illustrated in figure 21-5. Notice the angles at which the tool bits set in the various holders. These angles must be considered with respect to the angles ground in the tools and the angle that the toolholder is set with respect to the axis of the work.

Two types of toolholders that differ slightly from the common toolholders are those used for threading and knurling. (See figure 21-6.)

The threading toolholder has a formed cutter which needs to be ground only on the top surface for sharpening. Since the thread form is accurately shaped over a large arc of the tool, as the surface is worn away by grinding, the cutter can be rotated to the correct position and secured by the setscrew.

A knurling toolholder carries two knurled rolls which impress their patterns on the work as it revolves. The purpose of the knurling tool is to provide a roughened surface on round metal parts such as knobs, to give a better grip in handling. The knurled rolls come in a variety of patterns.

ENGINE LATHE TOOLS.—Figure 21-7 shows the most popular shapes of ground lathe tool cutter bits and their applications. In the following paragraphs each of the types shown is described.

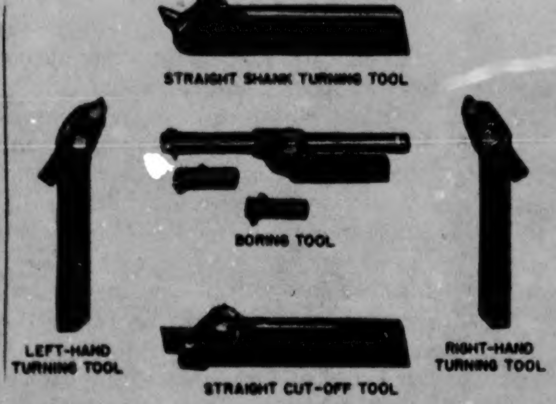

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Figure 21-5.—Common types of toolholders.

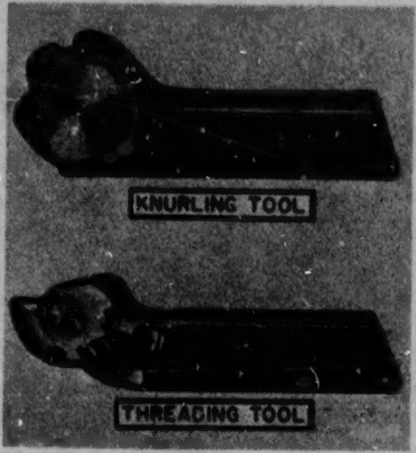

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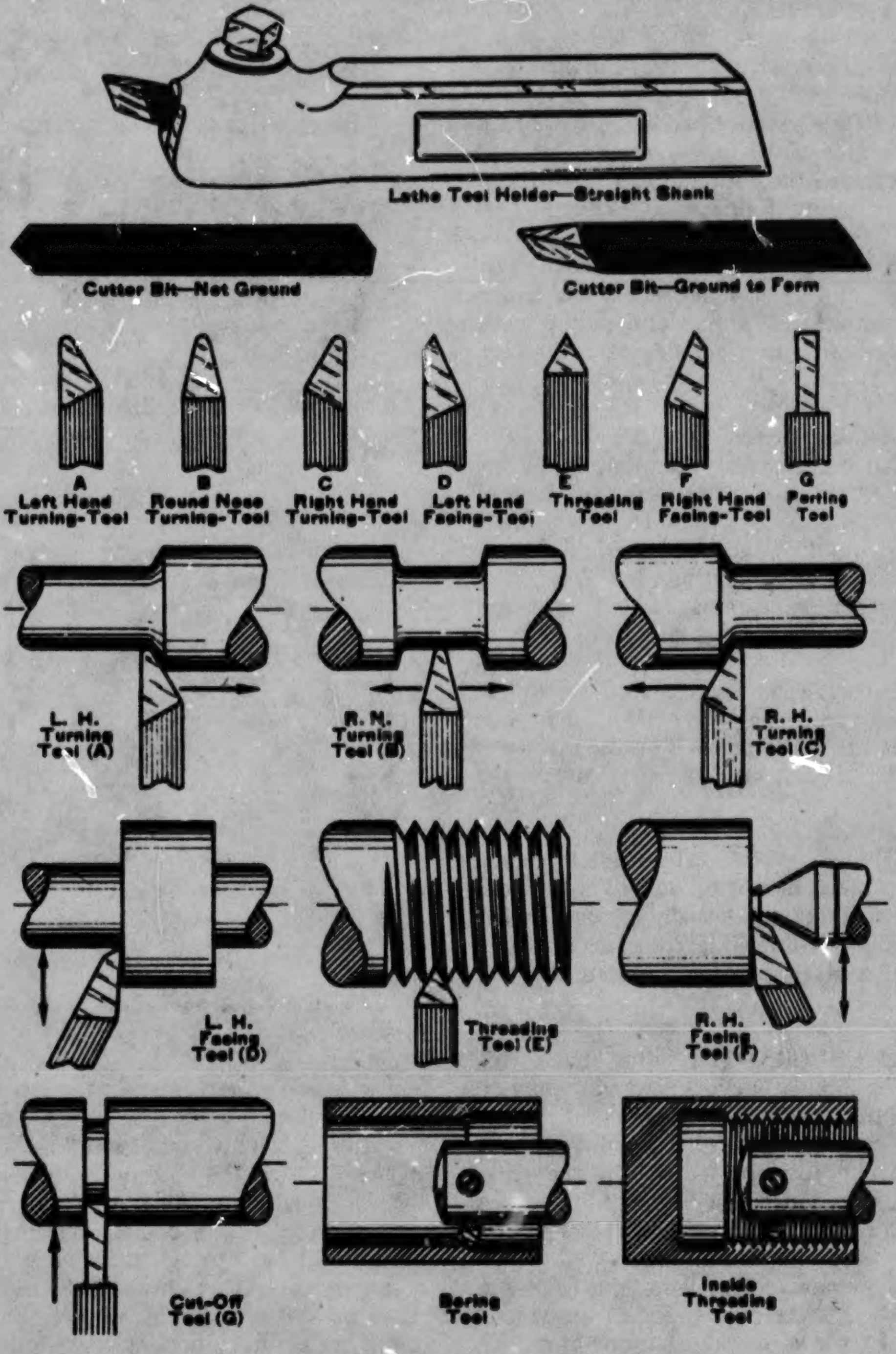
Figure 21-6.—Knurling and threading toolholders.

Left-Hand Turning Tool.—This tool is ground for machining work when fed from left to right, as indicated in A, figure 21-7. The cutting edge is on the right side of the tool, and the top of the tool slopes down away from the cutting edge.

Round-Nosed Turning Tool.—This tool is for general all-around machine work and is used for taking light roughing cuts and finishing cuts. Usually, the top of the cutter bit is ground with side rake so that the tool may be fed from right to left. Sometimes this cutter bit is ground flat on top so that the tool may be fed in either direction (B, fig. 21-7).

Right-Hand Turning Tool.—This is just the opposite of the left-hand turning tool and is designed to cut when fed from right to left (C, fig. 21-7). The cutting edge is on the left side. This is an ideal tool for taking roughing cuts and for general all-around machine work.

Left-Hand Facing Tool.—This tool is intended for facing on the left-hand side of the work, as shown in D, figure 21-7. The direction of feed is away from the lathe center. The cutting edge is on the right-hand side of the tool,


Lathe Tool Holder—Straight Shank
Cutter Bit—Not Ground
Cutter Bit—Ground to Form
A
Left Hand
Turning-Tool
B
Round Nose
Turning-Tool
C
Right Hand
Turning-Tool
D
Left Hand
Facing-Tool
E
Threading
Tool
F
Right Hand
Facing-Tool
G
Parting
Tool
L. H.
Turning
Tool (A)
R. N.
Turning
Tool (B)
R. H.
Turning
Tool (C)
L. H.
Facing
Tool (D)
Threading
Tool (E)
R. H.
Facing
Tool (F)
Cut-Off
Tool (G)
Boring
Tool
Inside
Threading
Tool

28.66

Figure 21-7.—Lathe tools and their application.

and the point of the tool is sharp to permit machining a square corner.

Threading Tool.–The point of the threading tool is ground to a 60° included angle for machining V-form screw threads (E, fig. 21-7). Usually, the top of the tool is ground flat, and there is clearance on both sides of the tool so that it will cut on both sides.

Right-Hand Facing Tool.–This tool is just the opposite of the left-hand facing tool and is intended for facing the right end of the work and for machining the right side of a shoulder. (See F, fig. 21-7.)

Square-Nosed Parting (Cutoff) Tool.–The principal cutting edge of this tool is on the front. (See G, fig. 21-7.) Both sides of the tool must have sufficient clearance to prevent binding and should be ground slightly narrower at the back than at the cutting edge. This tool is convenient for machining necks, grooves, squaring corners, and for cutting off.

Boring Tool.–The boring tool is usually ground the same shape as the left-hand turning tool so that the cutting edge is on the front side of the cutter bit and may be fed in toward the headstock.

Inside-Threading Tool.–The inside-threading tool is the same as the threading tool in E, figure 21-7, except that it is usually much smaller. Boring and inside-threading tools may require larger relief angles when used in small diameter holes.

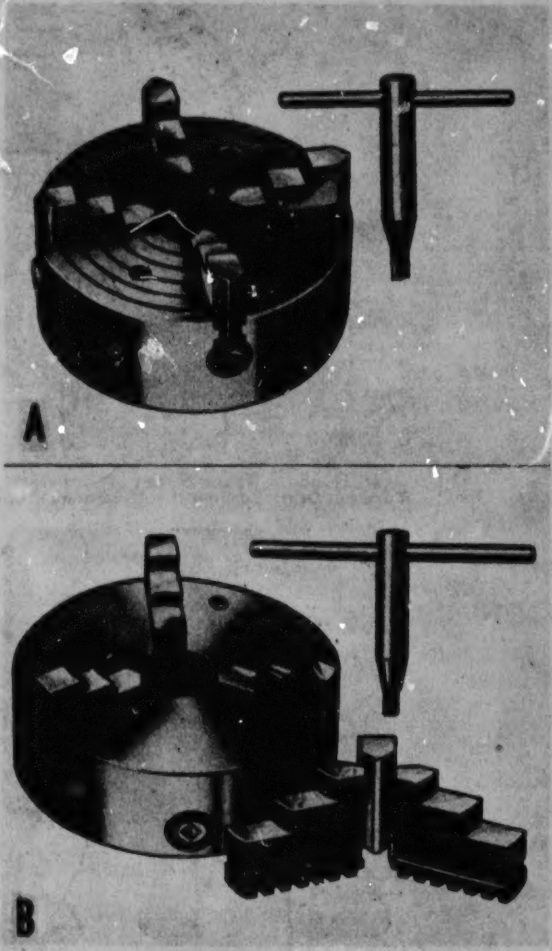


Figure 21-8.–A. 4-jaw chuck. B. 3-jaw chuck.

LATHE CHUCKS.–The lathe chuck is a device for holding lathe work. It is mounted on the nose of the spindle. The work is held by jaws which can be moved in radial slots toward the center to clamp down on the sides of the work. These jaws are moved in and out by screws turned by a chuck wrench applied to the sockets located at the outer ends of the slots.

The 4-jaw independent lathe chuck, part A in figure 21-8, is the most practical for general work. The four jaws are adjusted one at a time, making it possible to hold work of various shapes and to adjust the center of the work to coincide with the center of the lathe. The jaws are reversible.

The 3-jaw universal or scroll chuck, part B in figure 21-8, can be used only for holding round or hexagonal work. All three jaws are moved in and out together in one operation. They move universally to bring the work on center automatically. This chuck is easier to operate than the 4-jaw type, but, when its parts become worn, its accuracy in centering cannot be relied upon. Proper lubrication and constant care in use are necessary to ensure reliability.

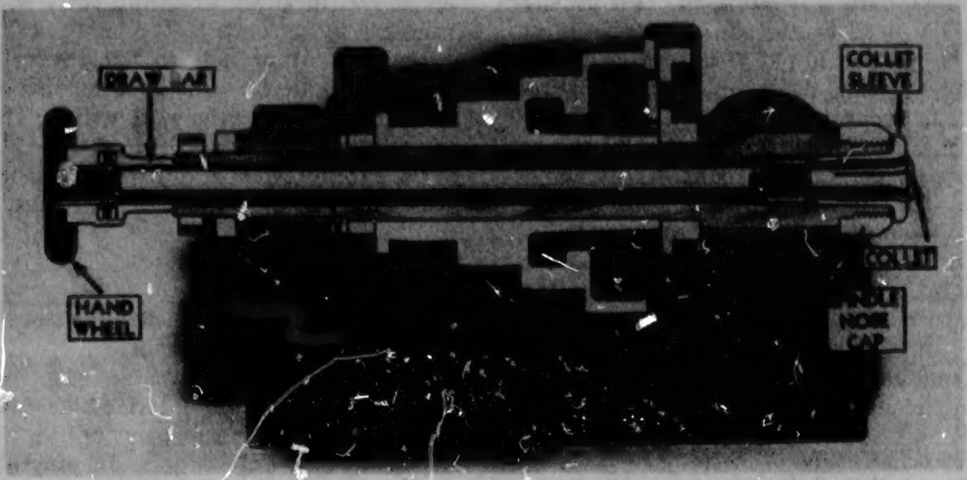


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Figure 21-9.–Draw-in collet chuck.

The draw-in collet chuck is used to hold small work for machining in the lathe. It is the most accurate type of chuck made and is intended for precision work. Figure 21-9 shows the parts assembled in place in the lathe spindle. The collet chuck which holds the work is a split-cylinder with an outside taper that fits into the tapered closing sleeve and screws into the threaded end of the hollow drawbar. Tightening up on the drawbar by turning the handwheel pulls the collet back into the tapered sleeve, thereby closing it firmly over the work and centering it accurately and quickly. The size of the hole in the collet determines the diameter of the work it can accommodate.

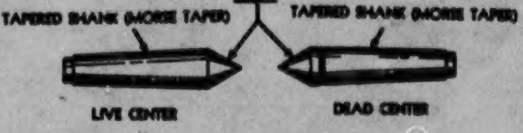
Faceplates

You will use the faceplate for holding work whose shape and dimensions cannot be swung on centers or in a chuck. The T-slots and other openings on its surface provide convenient anchors for bolts and clamps used in securing the work to it. The faceplate is mounted on the nose of the spindle.

The driving plate is similar to a small faceplate and is used principally for driving work that is held between centers. The radial slot receives the bent tail of a lathe dog clamped to the work and transmits rotary motion to the work.

Lathe Centers

The function of the 60° lathe centers shown in figure 21-10 is to provide a way to hold the work between points so it can be turned accurately on its axis. The head spindle center is called the LIVE CENTER because it revolves with the work. The tailstock center is called the DEAD CENTER because it does not turn. Both live and dead centers have shanks turned to a Morse taper to fit the tapered holes in the spindles; both have points finished to an angle of 60°. They differ only in that the dead center is hardened and tempered to resist the wearing effect of the work revolving on it. The live



28.93

Figure 21-10.–60° lathe centers.

center revolves with the work, and it is usually left soft. The dead center and live center must NEVER be interchanged. (There is a groove around the hardened dead center to distinguish it from the live center.)

The centers fit snugly in the tapered holes of the headstock and tailstock spindles. If chips, dirt, or burrs prevent a perfect fit in the spindles, the centers will not run true.

To remove the headstock center, insert a brass rod through the spindle hole and tap the center to jar it loose; it can then be picked out with the hand. To remove the tailstock center, run the spindle back as far as it will go by turning the handwheel to the left. When the end of the tailstock screw bumps the back of center, it will force it out of the tapered hole.

Lathe Dogs

Lathe dogs are used in conjunction with a driving plate or faceplate to drive work being machined on centers; the frictional contact alone between the live center and the work is not sufficient to drive it.

The common lathe dog, shown at the left in figure 21-11, is used for round work or work having a regular section (square, hexagon, octagon). The piece to be turned is held firmly in hole A by setscrew B. The bent tail C projects through a slot or hole in the driving plate or faceplate, so that, when the latter revolves with the spindle, it turns the work with it. The clamp dog, illustrated at the right in figure 12-11, may be used for rectangular or irregular shaped work. Such work is clamped between the jaws.

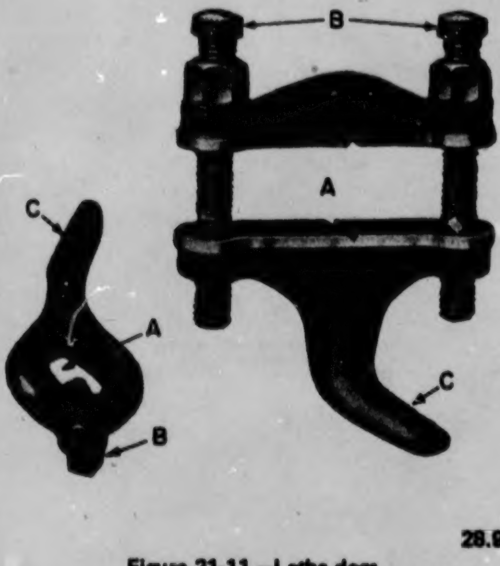


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Figure 21-11.—Lathe dogs.

Center Rest

The center rest, also called the steady rest, is used for the following purposes:

1. To provide an intermediate support or rest for long slender bars or shafts being machined between centers. It prevents them from springing under cut, or sagging as a result of their otherwise unsupported weight.

2. To support and provide a center bearing for one end of work, such as a spindle, being bored or drilled from the end when it is too long to be supported by a chuck alone. The center rest is clamped in the desired position on the bed on which it is properly aligned by the ways, as illustrated in figure 21-12. It is important that the jaws (A) be carefully adjusted to allow the work (B) to turn freely and at the same time keep it accurately centered on the axis of the lathe. To accomplish this, turn a short piece of scrap stock to the same diameter as the work to be held, then adjust the rollers to turn with light pressure. After applying the roller pressure, position the center rest where it is needed. The top half of the frame is hinged at C for easier positioning without removing the work from the centers or changing the position of the jaws.

Follower Rest

The follower rest is used to back up work of small diameter to keep it from springing under the stress of cutting. It can be set to either precede or follow the diameter reduction resulting from the cut taken by the cutting tool. As shown in figure 21-13, it is attached directly to the saddle by bolts (B). The adjustable jaws bear directly on the part of the work opposite the cutting tool.

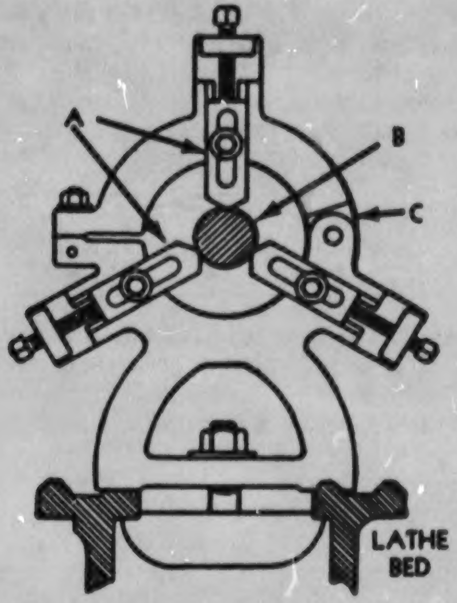

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Figure 21-12.–Center rest.

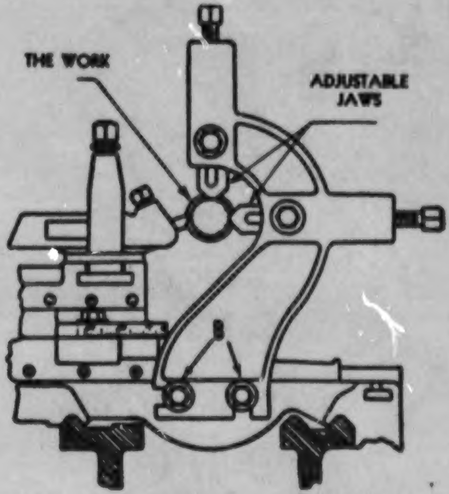

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Figure 21-13.–Follower rest.

Taper Attachment

The taper attachment, illustrated in figure 21-14 is used for turning and boring tapers. It is bolted to the back of the carriage saddle. In operation, it is so connected to the cross-slide that it moves the cross-slide laterally as the carriage moves longitudinally, thereby causing the cutting tool to move at an angle to the axis of the work to produce a taper.

The angle of the taper you desire to cut is set on the guide bar of the attachment. The guide bar support is clamped to the lathe bed. Since the cross-slide is connected to a shoe that slides on this guide bar, the tool follows along a line that is parallel to the guide bar and hence at an angle to the work axis corresponding to the desired taper.

The operation and application of the taper attachment will be further explained under the subject of taper work.

Thread Dial Indicator

The thread dial indicator, shown in figure 21-15, eliminates the need of reversing the lathe to return the carriage to the starting point to catch the thread at the beginning of each successive cut that is taken. The dial, which is

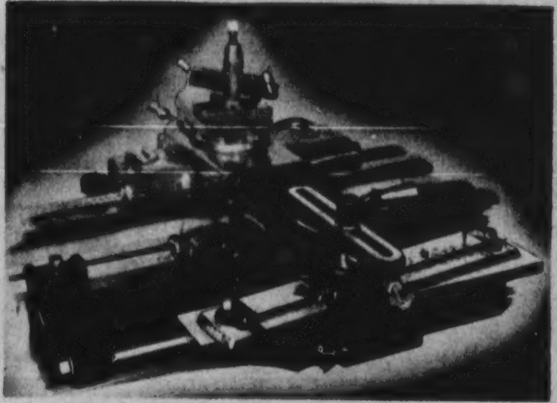

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Figure 21-14.–A taper attachment.

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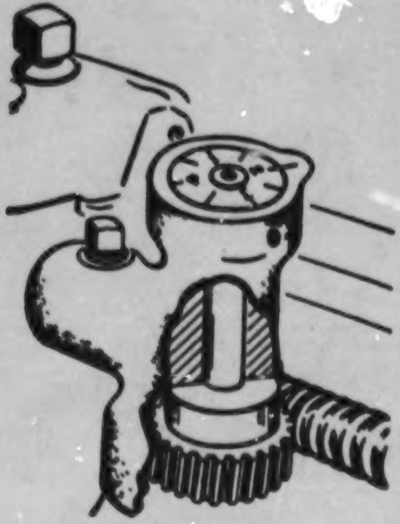

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Figure 21-15.—Thread dial indicator.

geared to the lead screw, indicates when to clamp the half-nuts on the lead screw for the next cut.

The threading dial consists of a worm wheel which is attached to the lower end of a shaft and meshed with the lead screw. On the upper end of the shaft is the dial. As the lead screw revolves, the dial is turned and the graduations on the dial indicate points at which the half-nuts may be engaged.

Carriage Stop

The carriage stop can be attached to the bed at any point where you desire to stop the carriage. It is used principally when turning, facing, or boring duplicate parts, as it eliminates the necessity of repeated measurements of the same dimension. In operation, the stop is set at the point where you want to stop the feed. Just before reaching this point, shut off the automatic feed and carefully run the carriage up against the stop. Carriage stops are provided with or without micrometer adjustment. Figure 21-16 shows a micrometer carriage stop. Clamp it on the ways in the approximate position required and then adjust it to the exact setting by the micrometer adjustment. (Do not confuse this stop with the automatic carriage stop that automatically stops the carriage by disengaging the feed or stopping the lathe.)

FACTORS RELATED TO MACHINING OPERATIONS

A knowledge of many factors is required if you are to be proficient in performing machine work with a lathe. Some of these factors are considered in the following sections.

PHASES OF THE OPERATION

Before attempting the operation of any lathe, make sure you know how to run it. Read all operating instructions supplied with the machine. Learn the locations of the various controls and how to operate them. When you are satisfied that you know how they work, start the motor, but first check to see that the spindle clutch and the power feeds are disengaged. Then

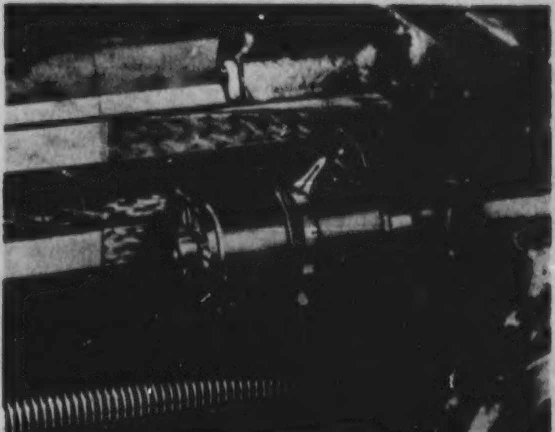

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Figure 21-16.—Micrometer carriage stop.

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become familiar with all phases of operation, as follows:

1. Shift the speed change levers into the various combinations; start and stop the spindle after each change. Get the feel of this operation.
2. With the spindle running at its slowest speed, try out the operation of the power feeds and observe their action. Take care not to run the carriage too near the limits of its travel. Learn how to reverse the direction of feeds and how to disengage them quickly. Before engaging either of the power feeds, operate the hand controls to be sure parts involved are free for running.
3. Try out the operation of engaging the lead screw for thread cutting. Remember that the feed mechanism must be disengaged before the half-nuts can be closed on the lead screw.
4. Practice making changes with the QUICK-CHANGE GEAR MECHANISM by referring to the thread and feed index plate on the lathe you intend to operate. Remember that changes made in the gear box are done with the lathe running slowly, but the lathe must be stopped for large changes made by shifting gears in the main gear train.

MAINTENANCE

The maintenance of any lathe must be done in strict compliance with the Maintenance and Material Management (3-M) System. Although the 3-M is designed to improve the degree of readiness, its effectiveness and reliability are dependent upon you. The first requisite to maintenance of your lathe is proper lubrication. Make it a point to oil your lathe daily where oil holes are provided. Oil the ways daily—not only for lubrication but to protect their scraped surfaces. Oil the lead screw often while in use; this is necessary to preserve its accuracy, for a worn lead screw lacks precision in thread cutting. Make sure the headstock is filled up to the oil level; drain it out and replace it when the oil becomes dirty or gummy. If your lathe is equipped with an automatic oiling system for some parts, make sure all those parts are getting oil. Make it a habit to CHECK frequently for lubrication of all moving parts.

Do not treat your machine roughly. When you shift gears for changing speed or feed, remember that you are putting solid gear teeth into mesh with each other; feel the gears in engagement. Disengage the clutch and stop the lathe before shifting.

Before engaging the longitudinal feed, be certain that the carriage clamp screw is loose and that the carriage can be moved by hand. Avoid running the carriage against the headstock or tailstock while under power feed; it puts an unnecessary strain on the lathe and may jam the gears.

Do not neglect the motor just because it may be out of sight; check its lubrication. If it does not run properly, notify the Electrician's Mate whose duty it is to care for it. He will cooperate with you to keep it in good condition. On lathes with a belt driven from the motor, avoid getting oil or grease on the belt when oiling the lathe or motor.

Keep your lathe clean. A clean and orderly machine is an indication of a good mechanic. Dirt and chips on the ways, on the lead screw, and on the crossfeed screws will cause serious wear and impair the accuracy of the machine.

NEVER put wrenches, files, or other tools on the ways. If you must keep tools on the bed, use a board to protect the finished surfaces of the ways.

NEVER use the bed or carriage as an anvil; remember that the lathe is a precision machine and nothing must be allowed to destroy its accuracy.

Cutting Speeds and Feeds

Cutting speed is the rate at which the surface of the work passes the point of the cutting tool. It is expressed in feet per minute.

Feed is the amount the tool advances in each revolution of the work. It is usually expressed in thousandths of an inch per revolution of the spindle. The index plate on the quick-change gear box indicates the setup for obtaining the feed desired. The amount of feed to use is best determined from experience.

Cutting speeds and tool feeds are determined by various considerations: the hardness and toughness of the metal being cut; the quality, shape, and sharpness of the cutting tool; the

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depth of the cut; the tendency of the work to spring away from the tool; and the strength and power of the lathe. Since conditions vary, it is good practice to find out what the tool and work will stand and then select the most practicable and efficient speed and feed consistent with the finish desired.

When ROUGHING parts down to size, use the greatest depth of cut and feed per revolution that the work, the machine, and the tool will stand at the highest practicable speed. On many pieces where tool failure is the limiting factor in the size of roughing cut, it is usually possible to reduce the speed slightly and increase the feed to a point where the metal removed is much greater. This will prolong tool life. Consider an example where the depth of cut is 1/4 inch, the feed 0.020 inch per revolution, and the speed 80 fpm. If the tool will not permit additional feed at this speed, it is usually possible to drop the speed to 60 fpm and increase the feed to about 0.040 inch per revolution without having tool trouble. The speed is therefore reduced 25% but the feed is increased 100% so that the actual time required to complete the work is less with the second setup.

On the FINISH TURNING OPERATION a very light cut is taken, since most of the stock has been removed on the roughing cut. A fine feed can usually be used, making it possible to run at a high surface speed. A 50% increase in speed over the roughing speed is commonly used. In particular cases the finishing speed may be twice the roughing speed. In any event, the work should be run as fast as the tool will withstand to obtain the maximum speed in this operation. A sharp tool should be used when finish turning.

COOLANTS

A cutting lubricant serves two main purposes–it cools the tool by absorbing a portion of the heat and reduces the friction between the tool and the metal being cut. A secondary purpose is to keep the cutting edge of the tool flushed clean.

The best lubricants to use for cutting metal must often be determined by experiment. Ordinary oil is often used, but water soluble oil is acceptable for most common metals. Special cutting compounds containing such ingredients as tallow, graphite, and lard, marketed under various names, are also used, but these are expensive and used mainly in manufacturing where high cutting speeds are the rule.

The usual lubricants for turning the following metals are:

Metal	Lubricant
Cast iron	Usually worked dry
Mild steel	Oil or soluble oil
Hard steel	Mineral lard oil
Monel metal	Dry (or soluble oil)
Bronze	Dry (or soluble oil)
Brass	Dry (or soluble oil)
Copper	Dry (or soluble oil)
Babbitt	Dry (or soluble oil)
Aluminum	Dry (or soluble oil)

For threading, a lubricant is more important than for straight turning. Mineral lard oil is recommended for threading in the majority of metals that are used by the Navy.

CHATTER

If you are unaware of the meaning of the word "chatter," you will learn all too soon while working with a machine tool of any description. Briefly, chatter is vibration in either the tool or the work. The finished work surface appears to have a grooved or lined finish instead of the smooth surface that is to be expected. The vibration is set up by a weakness in the work, work support, tool, or tool support and is about the most elusive thing to find in the entire field of machine work. As a general rule, strengthening the various parts of the tool support train will help. It is also advisable to support the work by a center rest or follower rest.

Possibly the fault is in the machine adjustments. Gibs may be too loose; bearings may, after a long period of heavy service, be worn; the tool may be sharpened improperly, etc. If the machine is in excellent condition, the fault may be in the tool or tool setup. Grind the tool with a point or as near a point as the finish specified will permit; avoid a wide, round leading edge on the tool. Reduce the overhang of the tool as much as possible and be sure that all the gib and bearing adjustments are properly made. See that the work receives proper support for the cut, and above all, do not try to turn at a surface speed that is too high. Excessive speed is probably the greatest cause of chatter, and the first thing you should do when chatter occurs is to reduce the speed.

Direction of Feed

Regardless of how the work is held in the lathe, the tool should feed toward the headstock. This results in most of the pressure of the cut being exerted on the workholding device and spindle thrust bearings. When it is necessary to feed the cutting tool toward the tailstock, take lignter cuts at reduced feeds. In facing, the general practice is to feed the tool from the center of the workpiece out toward the periphery.

PRELIMINARY PROCEDURES

Before starting a lathe machining operation, always ensure that the machine is set up for the job you are to do. If the work is mounted between centers, check the alignment of the dead center and the live center and make any changes required. Ensure that the toolholder and cutting tool are set at the proper height and angle. Check the workholding accessory to ensure that the workpiece is held securely. Use the center rest or follower rest for support of long workpieces.

PREPARING THE CENTERS

The first step in preparing the centers is to see that they are accurately mounted in the headstock and tailstock spindles. The centers and the tapered holes in which they are fitted must be perfectly clean. Chips and dirt left on the contact surfaces will impair accuracy by preventing a perfect fit of the bearing surfaces. Make sure that there are no burrs in the spindle hole. If burrs are found, remove them by carefully scraping or reaming with a Morse taper reamer. Burrs will produce the same inaccuracies as chips or dirt.

Center points must be finished accurately to an angle of 60°. Figure 21-17 shows the method of checking this angle with a center gage. The large notch of the center gage is intended for this particular purpose. If this test shows that the point is not perfect, you must true it in the lathe by taking a cut over the point with the compound rest set at 30°. You must anneal the hardened tail center before it can be machined in this manner, or you can grind it if a grinding attachment is available.

CHECKING ALIGNMENT

To turn a shaft straight and true between centers, the centers must be in a plane parallel to the ways of the lathe. You can move the tailstock laterally to accomplish this alignment by two adjusting screws after it has been released from the ways. At the rear of the tailstock are two zero lines, and the centers are approximately aligned when these two lines coincide. You can check this approximate alignment by moving the tailstock up until the centers almost touch and observing their relative positions as shown in figure 21-18. For very

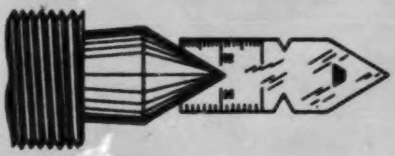

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Figure 21-17.—Checking center point with center gage.

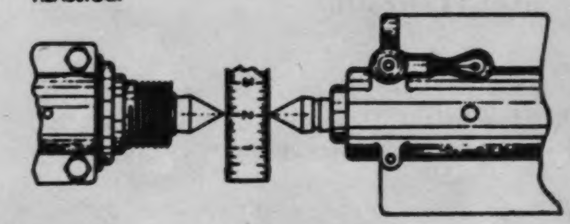

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Figure 21-18.—Aligning lathe centers.

accurate work, especially if it is long, the following test is necessary to correct small errors in alignment not otherwise detected.

Mount the work to be turned, or a piece of stock of similar length, on the centers. With a turning tool in the tool post, take a small cut to a depth of a few thousandths of an inch at the headstock end of the work. Then remove the work from the centers to allow the carriage to be run back to the tailstock without drawing the tool. Do not touch the tool setting. Replace the work in the centers, and, with the tool set at the previous depth, take another cut coming in from the tailstock end. Compare the diameters over these cuts with a micrometer. If the diameters are exactly the same, the centers are in perfect alignment. If they are different, you must adjust the tailstock in the direction required by turning the setover adjusting screws. Repeat the above test and adjustment until a cut at each end produces equal diameter.

You can also check the positive alignment of centers by placing a test bar between centers and bringing both ends of the bar to a zero reading as indicated by a dial indicator clamped in the tool post. The tailstock must be clamped to the ways and the test bar must be properly adjusted between centers when you take the indicator readings.

Another method that may be used for positive alignment of lathe centers is to take a light cut over the work held between centers. Then measure the work at each end with a micrometer, and, if the readings are found to differ, adjust the tailstock accordingly. Repeat the procedure until alignment is obtained.

SETTING THE TOOLHOLDER AND CUTTING TOOL

The first requirement for setting the tool is to have it rigid. Make sure the tool sets squarely in the tool post and that the setscrew is tight. Reduce overhang as much as possible to prevent springing when cutting. If the tool has too much spring, the point of the tool will catch in the work, causing chatter and damaging both the tool and the work. The distances represented by A and B in figure 21-19 show the correct overhang for the tool bit and the holder.

The point of the tool must be correctly positioned on the work. Place the cutting edge slightly above the center for straight turning of steel and cast iron and exactly on the center for all other work. To set the tool at the height desired, raise or lower the point of the tool by moving the wedge in or out of the tool post ring. By placing the point opposite the tail center point, you can adjust the setting accurately.

HOLDING THE WORK

Accurate work cannot be performed if work is improperly mounted. Requirements for proper mounting are:

1. The work centerline must be accurately centered with the axis of the lathe spindle.
2. The work must be rigidly held while being turned.
3. The work must NOT be sprung out of shape by the holding device.
4. The work must be adequately supported against any sagging caused by its own weight and against springing caused by the action of the cutting tool.

There are four general methods of holding work in the lathe: (1) between centers, (2) on a

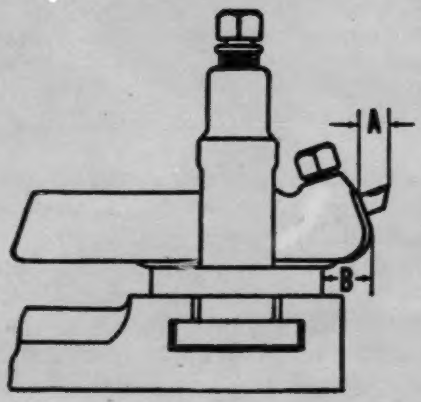

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Figure 21-19.—Tool overhang.

mandrel, (3) in a chuck, and (4) on a faceplate. Work may also be clamped to the carriage for boring and milling, in which case the boring bar or milling cutter is held and driven by the headstock spindle.

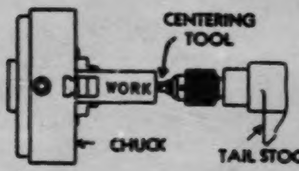
Other methods of holding work to suit special conditions are: (1) one end on the live center or in a chuck and the other end supported in a center rest, and (2) one end in a chuck and the other end on the dead center.

Holding Work Between Centers

To machine a workpiece between centers, center holes must be drilled in each end to receive the lathe centers. A lathe dog is then secured to the workpiece, and then the work is mounted between the live and dead centers of the lathe.

CENTERING THE WORK.–To center round stock where the ends are to be turned and must be concentric with the unturned body, the work can be held on the head spindle in a universal chuck or a draw-in collet chuck. If the work is long and too large to be passed through the spindle, a center rest must be used to support one end. The centering tool is held in a drill chuck in the tail spindle and is fed to the work by the tailstock handwheel (fig. 21-20).

For centerdrilling a workpiece, the combined drill and countersink is the most practical tool. These combined drills and countersinks vary in size and the drill points also vary. Sometimes a drill point on one end will be 1/8 inch in diameter, and the drill point on the opposite end will be 3/16 inch in diameter. The angle of the centerdrill is always 60° so that the countersunk hole will fit the angle of the lathe center point.



28.111

Figure 21-20.–Drilling center hole.

If a centerdrill is not available, the work may be centered with a small twist drill. Let the drill enter the work a sufficient length on each end; then follow with a special countersink, the point of which is 60°.

In centerdrilling, a drop or two of oil should be used on the drill. The drill should be fed slowly and carefully so as not to break the tip. Extreme care is needed when the work is heavy, because it is then more difficult to "feel" the proper feed of the work on the centerdrill.

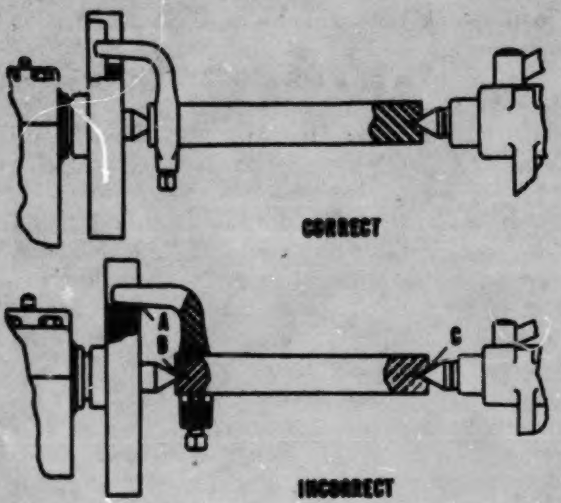
If the centerdrill breaks during countersinking and part of the broken drill remains in the work, this part must be removed. Sometimes it can be driven out by a chisel or jarred loose, but it may stick so hard that it cannot be removed in this manner. Then the broken part of the drill should be annealed and drilled out.

We cannot overemphasize the importance of proper center holes in the work and a correct angle on the point of the lathe centers. To do an accurate job between centers on the lathe, countersunk holes must be of the proper size and depth, and the points of the lathe centers must be true and accurate.

MOUNTING THE WORK.–Figure 21-21 shows correct and incorrect methods of mounting work between centers. In the correct example, the driving dog is attached to the work and rigidly held by the setscrew. The tail of the dog rests in the slot of the faceplate and extends beyond the base of the slot so that the work rests firmly on both the headstock center and tailstock center.

In the incorrect example, note that the tail of the dog rests on the bottom of the slot on the faceplate at A, thereby pulling the work away from the center points, as shown at B and C, and causing the work to revolve eccentrically.

In mounting work between centers for machining, there should be no end play between the work and the dead center. However, if the work is held too tightly by the tail center when revolving, the work will heat the center point, destroying both the center and the work. To help prevent overheating, the tail center must be lubricated with grease or oil.



28.115X

Figure 21-21.—Examples of work mounted between centers.

Holding Work on a Mandrel

Many parts, such as bushings, gears, collars, and pulleys require all the finished external surfaces to run true with the hole which extends through them. That is, the outside diameter must be true with the inside diameter or bore.

General practice is to finish the hole to a standard size within the limit of the accuracy desired. Thus a 3/4-inch standard hole would ordinarily be held from 0.7495 to 0.7505 inches; a tolerance of 0.0005 inch above or below the true standard size of exactly 0.750 inch. First drill or bore the hole to within a few thousandths of an inch of the finished size; then remove the remainder of the material with a machine reamer, following with a hand reamer if the limits are extremely close.

Then, press the piece on a mandrel tight enough so the work will not slip while being machined. Clamp a dog on the mandrel, which is mounted between centers. Since the mandrel surface runs true with respect to the lathe axis, the turned surfaces of the work on the mandrel will be true with respect to the hole in the piece.

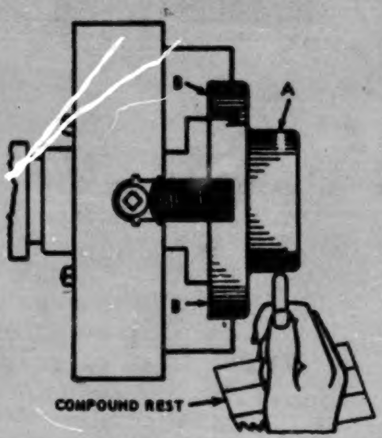
A mandrel is simply a round piece of steel of convenient length which has been centered and ground true with the centers. Commercial mandrels are made of tool steel, hardened and ground with a slight taper (usually 0.0005 inch per inch). On sizes up to 1 inch the small end is usually one-half thousandth of an inch under the standard size of the mandrel, while on larger sizes this dimension is usually 0.001 inch under standard. This taper allows the standard hole in the work to vary according to the usual shop practice and still provides a drive to the work when the mandrel is pressed into the hole. The taper is not great enough to distort the hole in the work. The countersunk centers of the mandrel are lapped for accuracy. The ends are turned smaller than the body of the mandrel and provided with flats which give a driving surface for the lathe dog.

Holding Work in Chucks

The independent chuck and universal chuck are more often used than other workholding devices in performing lathe operations. The universal chuck is used for holding relatively true cylindrical work when the time required to do the job is more important than the accurate concentricity of the machined surface and the holding power of the chuck. When the work is irregular in shape and must be accurately centered and held securely for heavy feeds and depth of cuts, an independent chuck should be used.

4-JAW INDEPENDENT CHUCK.—Figure 21-22 shows a rough casting mounted in a 4-jaw independent lathe chuck on the spindle of the lathe. Before truing the work, determine which part you wish to have turn true. To mount this casting in the chuck, proceed as follows:

1. Adjust the chuck jaws to receive the casting. Each jaw should be concentric with the ring marks indicated on the face of the chuck. If there are no ring marks, be guided by the circumference of the body of the chuck.
2. Fasten the work in the chuck by turning the adjusting screw on jaw No. 1 and jaw No. 3, a pair of jaws which are opposite to each other. Next tighten jaws No. 2 and No. 4.
3. At this stage the work should be held in the jaws just tight enough so it will not fall out of the chuck while being trued.



28.119

Figure 21-22.–Work mounted in a 4-jaw chuck.

4. Revolve the spindle slowly by hand and, with a piece of chalk, mark the high spot (A in figure 21-22) on the work while it is revolving. Steady your hand on the tool post while holding the chalk.

5. Stop the spindle. Locate the high spot on the work and adjust the jaws in the proper direction to true the work by releasing the jaw opposite the chalk mark and tightening the one nearest the mark.

6. Sometimes the high spot on the work will be located between adjacent jaws. In that case, loosen the two opposite jaws and tighten the jaws adjacent to the high spot.

3-JAW UNIVERSAL CHUCK.–The 3-jaw universal or scroll chuck is made so that all jaws move together in unison. A universal chuck will center almost exactly at the first clamping, but after a period of use it is not uncommon to find inaccuracies of up to 0.010 inch in centering the work, and consequently the runout of the work must be corrected. Sometimes this may be done by inserting a piece of paper or thin shim stock between the jaw and the work on the high side.

After you have done the positioning in a chuck, be sure to tighten all the screws so that each jaw is tight against the piece to prevent it from slipping when being cut.

When chucking thin sections, be careful not to clamp the work too tightly because the diameter of the piece will be machined when it is in a distorted position. When the pressure of the jaws is released after the cut, there will be as many high spots as there are jaws, and the turned surface will not be true.

Care of Chucks

To preserve the accuracy of a chuck, handle it carefully and keep it clean and free from grit. NEVER force a chuck jaw by using a pipe as an extension on the chuck wrench.

Before mounting a chuck, you must remove the live center to prevent the possibility of ruining it when drilling work held in the chuck (you could inadvertently drill right through the center).

CLEAN AND OIL THE THREADS OF THE CHUCK AND THE SPINDLE NOSE.–Dirt or chips on the threads will not allow the chuck to run true when it is screwed up to the shoulder. Screw the chuck on carefully. Avoid bringing it up against the shoulder so fast that the chuck comes up with a shock, since this will strain the spindle and the threads and make removal difficult. Never use mechanical power in screwing on the chuck. Rotate the spindle with the left hand while holding the chuck in the hollow of the right arm.

To remove a small chuck, place an adjustable jaw wrench on one of the jaws and start it by a smart blow with the hand on the handle of the wrench. To remove a heavy chuck, rotate it against a block of wood held between a jaw and the lathe bed. When mounting or removing a heavy chuck, lay a board across the bed ways to protect them; the board will serve as a support for the chuck as it is put on or taken off.

The above comments on mounting and removing chucks also apply to faceplates.

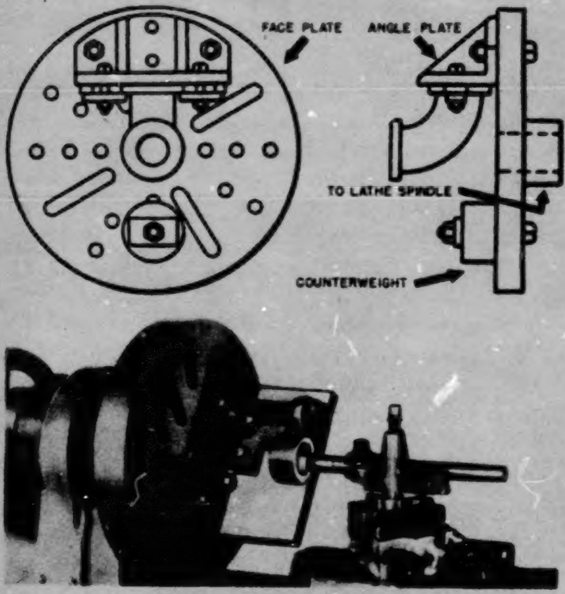
Holding Work on a Faceplate

A faceplate is used for mounting work which cannot be chucked or turned between centers. This may occur because of the peculiar shape of the work. A faceplate may be used when holes are to be accurately machined in flat work or when large and irregularly shaped work is to be faced on the lathe.

Work is secured to the faceplate by bolts, clamps, or any suitable clamping means. The holes and slots in the faceplate are used for anchoring the holding bolts. Angle plates may be used to present the work at the desired angle, as shown in figure 21-23. Note the counterweight added for balance.

For work to be mounted accurately on a faceplate, the surface of the work in contact with the faceplate must be accurately faced. It is good practice to place a piece of paper between the work and the faceplate to prevent slipping.

Before securely clamping the work, you must move it about on the surface of the faceplate until the point to be machined is centered accurately over the axis of the lathe. Suppose you wish to bore a hole, the center of which has been laid out and marked with a prick punch. First, clamp the work to the approximate position on the faceplate. Slide the tailstock up until the dead center just touches the work. (Note: The dead center should have a sharp, true point.) Now revolve the work slowly; if the work is off center, the point will scribe a circle on the work. If the work is on center, the point of the dead center will coincide with the prick punch mark.



28.124X
Figure 21-23.—Work clamped to an angle plate.

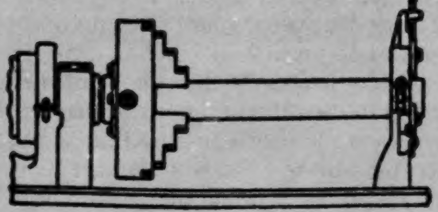
Using the Center Rest and Follower Rest

In addition to being supported at the ends by the lathe centers, long slender work often requires support between ends while being turned; otherwise the work will spring away from the tool and chatter. The center rest is used to support such work so it can be accurately turned with a faster feed and cutting speed than would be possible without it.

The center rest should be placed where it will give the greatest support to the piece to be turned. This is usually at about the middle of its length.

Ensure that the center point between the jaws of the center rest coincides exactly with the axis of the lathe spindle. To do this, place a short piece of stock in a chuck and machine it to the diameter of the workpiece to be supported. Without removing the stock from the chuck, clamp the center rest on the ways of the lathe and adjust the jaws to the machined surface. Without changing the jaw settings, slide the center rest into position to support the workpiece. Remove the stock used for setting the center rest and set the workpiece in place. Use a dial indicator to true the workpiece at the chuck. Figure 21-24 shows how a chuck and center rest are used for machining the end of a workpiece.

The follower rest differs from the center rest in that it moves with the carriage and provides



28.126X
Figure 21-24.—Work mounted in a chuck and center rest.

support against the forces of the cut only. Set the tool to the diameter selected, and turn a "spot" about 5/8 to 3/4 inch wide. Then adjust the follower rest jaws to the finished diameter to follow the tool along the entire length to be turned.

Use a thick oil on the jaws of the center rest and follower rest to prevent "seizing" and scoring the workpiece. Check the jaws frequently to see that they do not become hot. The jaws may expand slightly if they get hot, pushing the work out of alignment (when using the follower rest) or binding (when using the center rest).

Holding Work in a Draw-In Collet Chuck

The draw-in collet chuck is used for very fine accurate work of small diameter. Long work can be passed through the hollow drawbar, and short work can be placed directly into the collet from the front. The collet is tightened on the work by rotating the drawbar to the right; this draws the collet into the tapered closing sleeve. The opposite operation releases the collet.

Accurate results are obtained when the diameter of the work is exactly the same size as the dimension stamped on the collet. In some cases, the diameter may vary as much as 0.002 inch; that is, the work may be 0.001 inch smaller or larger than the collet size. If the work diameter varies more than this, it will impair the accuracy and efficiency of the collet. That is why a separate collet should be used for each small variation or work diameter, especially if precision is desired.

MACHINING OPERATIONS

Up to this point, you have studied the preliminary steps leading to the performance of machine work in the lathe. You have learned how to mount the work and the tool and which tools are used for various purposes. Now, you need to consider the method of using the proper tools in combination with the lathe to perform various machining operations.

FACING

Facing is the machining of the end surfaces and shoulders of a workpiece. In addition to squaring the ends of the work, facing provides a means of accurately cutting the work to length. Generally, in facing the workpiece, only light cuts are required as the work will have been cut to approximate length or rough machined to the shoulder.

Figure 21-25 shows the method of facing a cylindrical piece. The work is placed on centers and driven by a dog. A right-hand side tool is used as shown. Take a light cut on the end of the work, feeding the tool (by hand crossfeed) from the center toward the outside. Take one or two chips to remove enough stock to true the work. Then place the dog on the other end of the work and face it to the proper length. To provide an accurate base from which to measure, hold another rule or straightedge on the end that has just been faced. Be sure there is no fin or burr on the edge to keep the straightedge from bearing accurately on the finished end. Use a sharp scriber to mark off the dimension desired.

Figure 21-26 shows the application of a turning tool in finishing a shouldered job having a fillet corner. Take a finish cut on the small diameter. Machine the fillet with a light cut; then use the tool to face from the fillet to the outside of the work.

In facing large surfaces, lock the carriage in position, since only crossfeed is required to transverse the tool across the work. With the compound rest set at 90° (parallel to the axis of the lathe), you can use the micrometer collar to feed the tool to the proper depth of cut in the face.

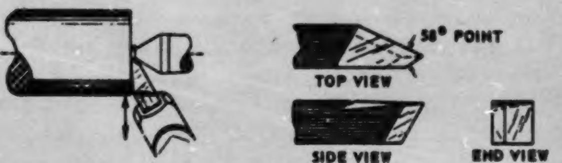


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Figure 21-25.—Facing a cylindrical piece.

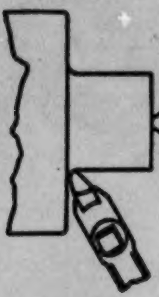

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Figure 21-26.—Facing a shoulder.

TURNING

Turning is the machining of excess stock from the periphery of the workpiece to reduce the diameter. In most lathe machining operations requiring removal of large amounts of stock, a series of roughing cuts is taken to remove most of the excess stock; then a finishing cut is taken to accurately "size" the workpiece.

Rough Turning

When a great deal of stock is to be removed, you should take heavy cuts to complete the job in the least possible time. This is called rough turning.

Select the proper tool for taking a heavy chip. The speed of the work and the amount of feed of the tool should be as great as the tool will stand.

When taking a roughing cut on steel, cast iron, or any other metal that has a scale upon its surface, be sure to set the tool deep enough to get under the scale in the first cut. Unless you do, the scale on the metal will dull or break the point of the tool.

Rough machine the work to almost the finished size; then take careful measurements.

Bear in mind that the diameter of the work being turned is reduced by an amount equal to twice the depth of the cut; thus, if you desire to reduce the diameter of a piece by 1/4 inch, you must remove 1/8 inch of metal from the surface.

Figure 21-27 shows the position of the tool for taking a heavy cut on large work. Set the tool so that, if anything occurs while machining to change the position of the tool, it will not dig into the work, but rather it will move in the direction of the arrow—away from the work.

Finish Turning

When the work has been rough turned to within about 1/32 inch of the finished size, take a finishing cut. A fine feed, the proper lubricant, and above all a keen-edged tool are necessary to produce a smooth finish. Measure carefully to be sure that you are machining the work to the proper dimension. Stop the lathe when measuring.

Where very close limits are to be held, be sure the work is not hot when you take the finish cut. Cooling of the piece will leave it undersized if it has been turned to the exact size.

Perhaps the most difficult operation for a beginner in machine work is to make accurate measurements. So much depends on the accuracy of the work that you should make every effort to become proficient in the use of measuring instruments. A certain "feel" in the application of micrometers is developed through experience alone; do not be discouraged if your first efforts do not produce perfect results. Practice taking micrometer measurements on pieces of known dimensions. You will acquire skill if you are persistent.

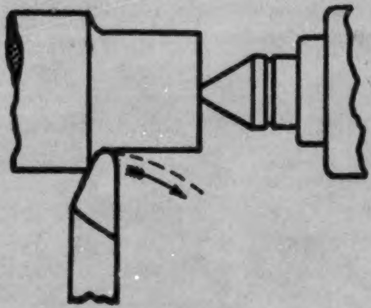

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Figure 21-27.—Position of tool for heavy cut.

Turning to a Shoulder

Machining to a shoulder is often done by locating the shoulder with a parting tool. Insert the parting tool about 1/32 inch back of the shoulder line; it will enter the work within 1/32 inch of the smaller diameter of the work. Then machine the stock by taking heavy chips up to the shoulder thus made. Shouldering eliminates detailed measuring and speeds up production.

Figure 21-28 illustrates the method of shouldering. A parting tool has been used at P and the turning tool is taking a chip. It will be unnecessary to waste any time in taking measurements. You can devote your time to rough machining until the necessary stock is removed. Then you can take a finishing cut to accurate measurement.

Boring

Boring is the machining of holes or any interior cylindrical surface. The piece to be bored must have a drilled or cored hole, and the hole must be large enough to insert the tool. The boring process merely enlarges the hole to the desired size or shape. The advantage of boring is that a perfectly true round hole is obtained, and two or more holes of the same or different diameters may be bored at one setting, thus ensuring absolute alignment of the axis of the holes.

It is the usual practice to bore a hole to within a few thousandths of an inch of the desired size and then finish it with a reamer to the exact size.

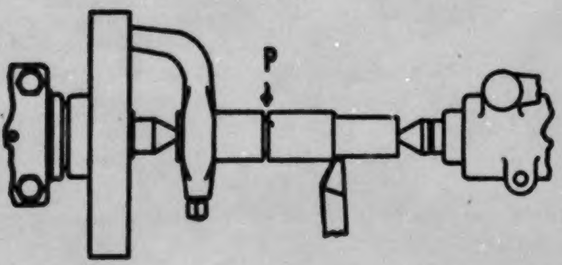

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Figure 21-28.–Machining to a shoulder.

Work to be bored may be held in a chuck, bolted to the faceplate, or bolted to the carriage. Long pieces must be supported at the free end in a center rest.

When the boring tool is fed into the hole in work being rotated on a chuck or faceplate, the process is called single point boring. It is the same as turning except that the cutting chip is taken from the inside. The cutting edge of the boring tool resembles that of a turning tool. Boring tools may be the solid forged type or the inserted cutter bit type.

When the work to be bored is clamped to the top of the carriage, a boring bar is held between centers and driven by a dog. The work is fed to the tool by the automatic longitudinal feed of the carriage. Three types of boring bars are shown in figure 21-29. Note the countersunk center holes at the ends to fit the lathe centers.

Figure 21-29 (A) shows a boring bar fitted with a fly cutter held by a headless setscrew. The other setscrew, bearing on the end of the cutter, is for adjusting the cutter to the work.

Figure 21-29 (B) shows a boring bar fitted with a two-edged cutter held by a taper key. This is more of a finishing or sizing cutter, as it cuts on both sides and is used for production work.

The boring bar shown in figure 21-29 (C) is fitted with a cast-iron head to adapt it for boring work of large diameter. The head is fitted with a

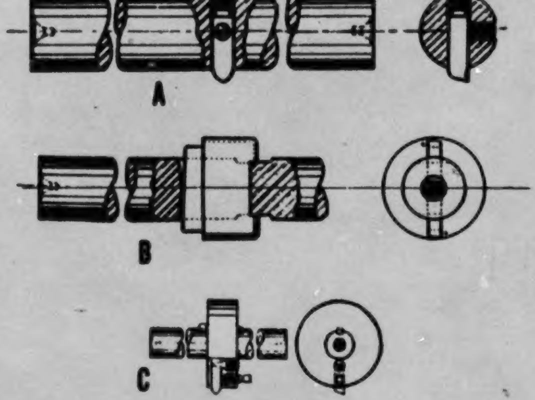

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Figure 21-29.–Boring bars.

fly cutter similar to the one shown in part A of figure 21-29. The setscrew with the tapered point adjusts the cutter to the work.

TAPERS

The term "taper" may be defined as the gradual lessening of the diameter or thickness of a piece of work toward one end. The amount of taper in any given length of work is found by subtracting the size of the small end from the size of the large end. Taper is usually expressed as the amount of taper per foot of length, or as an angle.

We will take two examples as an illustration.

Example 1.–Find the taper per foot of a piece of work 2 inches long: Diameter of small end is 1 inch; diameter of the large end is 2 inches.

The amount of taper is 2 inches minus 1 inch, which equals 1 inch. The length of the taper is given as 2 inches. Therefore, the taper is 1 inch in 2 inches of length. In 12 inches of length it would be 6 inches. (See fig. 21-30.)

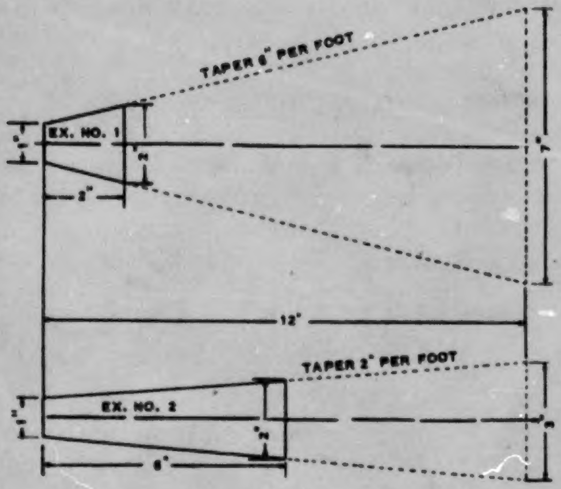

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Figure 21-30.–Tapers.

Example 2.–Find the taper per foot of a piece 6 inches long. Diameter of small end is 1 inch; diameter of large end is 2 inches.

The amount of taper is the same as in problem 1, that is, 1 inch. However, the length of this taper is 6 inches; hence the taper per foot is 1 inch X 12/6 = 2 inches per foot (fig. 21-30).

From the foregoing, you see that the length of a tapered piece is very important in computing the taper. If you bear this in mind when machining tapers, you will not go wrong. Using the formula:

$$\text{Taper per foot} = T \times \frac{12}{L}$$

where T represents the amount of taper in length L, both expressed in inches.

Now let us consider the angle of the taper. In a round piece of work, the included angle of the taper is twice the angle that the surface makes with the axis or centerline. In straight turning, recall that the diameter of a piece is reduced by twice the depth of the cut taken from its surface. For the same reason, the included angle of the taper is twice the angle that the path of the cutting tool makes with the axis or centerline of the piece being turned. There are tables or charts in all machinist's handbooks that give the angles for different amounts of taper per foot.

There are three standard tapers with which you should be familiar:

1. The MORSE TAPER (approximately 5/8 inch per foot) is used for the taper holes in lathe and drill press spindles and the attachments that fit them, such as lathe centers, drill shanks, etc.

2. The BROWN & SHARPE TAPER (1/2 inch per foot except No. 10 which is 0.5161 inch per foot) is used for milling machine spindle shanks.

3. The JARNO TAPER (0.6 inch per foot) is used by some manufacturers because of its simplicity, it being the only taper that is

constant and does not require a table to find the various dimensions pertaining to its parts; e.g.

$$\text{Diameter of large end} = \frac{\text{taper number}}{8}$$

$$\text{Diameter of small end} = \frac{\text{taper number}}{10}$$

$$\text{Length of taper} = \frac{\text{taper number}}{2}$$

The taper for pipe ends, 3/4 inch per foot, is also considered a standard.

Turning Tapers

In ordinary straight turning, the cutting tool moves along a line parallel to the axis of the work, causing the finished job to be the same diameter throughout. If, however, in cutting, the tool moves at an angle to the axis of the work, a taper will be produced. Therefore, to turn a taper, you must mount the work in the lathe so the axis upon which it turns is at an angle to the axis of the lathe, or cause the cutting tool to move at an angle to the axis of the lathe.

There are three methods in common use for turning tapers:

1. Setting over the tailstock, which moves the dead center away from the axis of the lathe and causes work supported between centers to be at an angle with the axis of the lathe.
2. Using the compound rest set at an angle and causing the cutting tool to be fed at the desired angle to the axis of the lathe.
3. Using the taper attachment, which also causes the cutting tool to move at an angle to the axis of the lathe.

In the first method, the cutting tool is fed by the longitudinal feed parallel to the lathe axis, but a taper is produced because the work axis is at an angle. In the second and third methods, the work axis coincides with the lathe axis, but a taper is produced because the cutting tool moves at an angle.

SETTING OVER THE TAILSTOCK.–The tailstock top may be moved laterally on its base by means of adjusting screws. In straight turning, you will recall that these adjusting screws were used to align the dead center with the tail center by moving the tailstock to bring it on the centerline. For taper turning, you deliberately move the tailstock off-center, and the amount you move it determines the taper produced. The amount of setover can be approximately set by means of the zero lines inscribed on the base and top of the tailstock as shown in figure 21-31.

In turning a taper by this method, the distance between centers is of utmost importance. To illustrate, figure 21-32 shows two very different tapers produced by the same amount of setover of the tailstock, because in one case the length of the work between centers is greater than in the other. THE CLOSER THE DEAD CENTER IS TO THE LIVE CENTER, THE STEEPER THE TAPER PRODUCED.

Suppose you want to turn a taper on the full length of a piece 12 inches long with one end having a diameter of 3 inches and the other end a diameter of 2 inches. The small end is to be 1

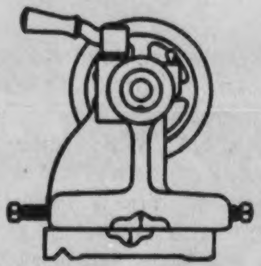

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Figure 21-31.–Tailstock setover for taper turning.

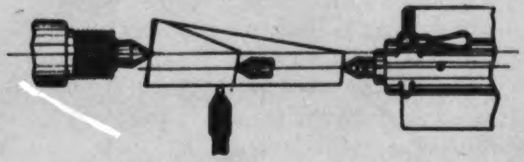

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Figure 21-32.–Setover of tailstock showing importance of considering length of work.

inch smaller than the large end; so you set the tailstock over one-half this amount or 1/2 inch. Thus, at one end the cutting tool will be 1/2 inch closer to the center of the work than at the other end; so the diameter of the finished job will be 2 X 1/2 or 1 inch less at the small end. Since the piece is 12 inches long, you have produced a taper of 1 inch per foot. Now, if you wish to produce a taper of 1 inch per foot on a piece only 6 inches long, the small end would be only 1/2 inch less in diameter than the large end, so you would set the tailstock over 1/4 inch or one-half of the distance used for the 12-inch length.

From the foregoing, you can see that the setover is proportional to the length between centers and may be computed by the following formula:

$$S = \frac{T}{2} \times \frac{L}{12}$$

where S = setover in inches, T = taper per foot in inches, and L ÷ 12 = length in feet.

Remember that L is length of work from live center to dead center. If the work is on a mandrel, L is the length of the mandrel between centers.

The setover tailstock method cannot be used for steep tapers because the setover necessary would be too great and the work would not be properly supported by the lathe centers. It is obvious that with setover there is not a true bearing between the points of work centers and the lathe centers and that the bearing surface becomes less and less satisfactory as the setover is increased.

After turning a taper by the tailstock setover method, realign the centers for straight turning for your next job.

USING THE COMPOUND REST.–The compound rest is generally used for short, steep tapers. It is set at the angle which the taper is to make with the centerline (that is, half the included angle of the taper). The tool is then fed to the work at this angle by means of the compound rest feed screw. The length of taper that can be machined is necessarily short because of limited travel of the compound rest top.

Truing a lathe center is one example of the use of the compound rest for taper work. Other examples are refacing an angle type valve disk, machining the face of a bevel gear, and similar work. Such jobs are often referred to as working to an angle rather than as taper work.

The graduations marked on the compound rest provide a quick means for setting to the angle desired. When set at zero, the compound rest is perpendicular to the lathe axis. When set at 90° on either side, the compound rest is parallel to the lathe axis.

On the other hand, when the angle to be cut is measured from the centerline, the setting of the compound rest corresponds to the complement of that angle. (The complement of an angle is that angle which added to it makes a right angle; that is, angle plus complement = 90°). For example, to machine a 50° included angle (25° angle with centerline), the compound rest is set at 90° - 25°, or 65°.

When a very accurate setting of the compound rest is to be made to a fraction of a degree, for example, run the carriage up to the faceplate and set the compound rest with a vernier bevel protractor set to the required angle. Hold the blade of the protractor on the flat surface of the faceplate and hold the stock against the finished side of the compound rest.

USING THE TAPER ATTACHMENT.–For turning and boring long tapers with accuracy, the taper attachment is indispensable. It is especially useful in duplicating work; identical tapers can be turned and bored with one setting of the taper guide bar.

Set the guide bar at an angle to the lathe axis corresponding to the taper desired. The tool cross-slide moves laterally by means of a shoe which slides on the guide bar as the carriage moves longitudinally. As a result, the cutting tool moves along a line parallel to the guide bar, and produces a taper whose angular measurement is the same as that set on the guide bar. The guide bar is graduated in degrees at one end and in inches per foot of taper at the other end to facilitate rapid setting.

When preparing to use the taper attachment, run the carriage up to the approximate position of the work to be turned. Set the tool on line with the centers of the lathe. Then bolt or clamp the holding bracket to the ways of the bed (the attachment itself is bolted to the back of the carriage saddle) and tighten clamp C (figure 21-33). The taper guide bar now controls the lateral movement of the cross-slide. Set the guide bar for the taper desired, and the attachment is ready for operation. The final adjustment of the tool for size must be made by means of the compound rest feed screw, since the crossfeed screw is inoperative.

Taper Boring

Taper boring may be accomplished only by using the compound rest or the taper attachment.

The rules that apply to outside taper turning also apply to the boring of tapered holes. Place the cutting point of the tool on center and, if you use the taper attachment, be very careful to eliminate the backlash of the slide fittings so that the hole will not be bored straight at the start. Measurement of the size and taper of the hole is generally made with a taper plug gage by the cut and try method. After taking a cut or two, clean the bore, rub the gage lightly with prussian blue inserted in the hole, and twist slightly to cause the prussian blue to show where the gage is bearing. Make any necessary corrections and continue the boring until the taper is brought to size.

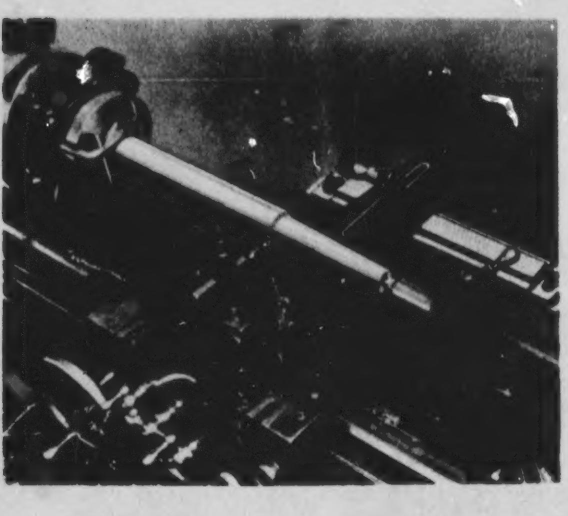

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Figure 21-33.—Turning a taper using taper attachment.

To make a blind tapered hole, such as may be required in drill sockets, it is best to drill the hole carefully to the correct depth with a drill of the same size as specified for the small end of the hole. This gives the advantage of boring to the right size without removing metal at the extreme bottom of the bore, which is rather difficult, particularly in small, deep holes.

For turning and boring tapers, set the tool cutting edge exactly at the center of the work. That is, set the point of the cutting edge even with the height of the lathe centers.

To test the taper on a nearly finished piece of work that is to fit a spindle, use prussian blue along the element or side of the taper piece. Place the work in the taper hole it is to fit and turn carefully by hand. Then remove the work and the prussian blue mark will show where the taper is bearing. If it is a perfect fit, it will indicate along the entire line of the prussian blue mark. If it is not, it will show where the adjustment is needed. Make the adjustment, take another light chip and test again. Be sure the taper is correct before turning to the finished diameter.

Figure 21-34 shows a Morse standard taper plug and a taper socket gage. They not only give the proper distance that the taper should enter the spindle, but also show the proper distance that the taper should enter the spindle.

SAFETY PRECAUTIONS

In machining operations, safety must always be kept in mind, no matter how important the job is or how well you know the machine you

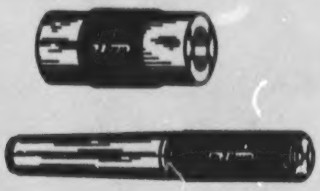

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Figure 21-34.—Morse taper socket gage and plug gage.

are operating. Listed below are some safety precautions that you MUST follow:

1. Before starting any lathe operations, always prepare yourself by rolling up shirt sleeves and removing watches, rings and other jewelry that might become caught while operating the machine.

2. Wear goggles or an approved face shield at all times when operating a lathe or when in the area of a lathe that is being operated.

3. Be sure the work area is clear of obstructions that you might fall or trip over.

4. Keep the area around your machine clear of oil or grease on the deck to prevent the possibility of slipping or falling into the machine.

5. Always use assistance when handling large pieces of work on large chucks.

6. NEVER remove chips with your bare hands. Use a stick or brush, and always stop the machine.

7. Always secure power to the machine when taking measurements or making adjustments to the chuck.

8. Be attentive, not only to the operation of your machine, but also to events going on around it. Skylarking should NEVER be permitted in the area.

9. Should it become necessary to operate the lathe while underway, be especially safety conscious. (Machines should be operated ONLY in relatively calm seas.)

10. Be alert to the location of the cutting tool while taking measurements or making adjustments.

11. Always observe the specific safety precautions posted for the machine you are operating.

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APPENDIX I

GLOSSARY

ABSOLUTE PRESSURE: Actual pressure (includes atmospheric pressure).

ABSOLUTE TEMPERATURE: The temperature measured using absolute zero as a reference. Absolute zero is -273.16°C or -459.69°F.

ABT (automatic bus transfer): An automatic electrical device that supplies power to vital equipment. This device will shift from the normal power supply to an alternate power supply anytime the normal supply is interrupted.

ACCELERATION: Time rate of change in velocity.

ACCESSORY DRIVE: A drive consisting of gears, chains, or belts of secondary importance, not essential in itself but essential for the operation of engine accessories (fuel pump, water pump, etc).

ACCUMULATOR: A device for storing liquid under pressure, usually consisting of a chamber separated into a gas compartment and a liquid compartment by a piston or diaphragm. An accumulator also serves to smooth out pressure surges in a hydraulic system.

ACETYLENE: A gas that is chemically produced from calcium carbide and water, used for welding and cutting.

ACTUATOR: A device that converts fluid power into mechanical force and motion.

ADDITIVE: A chemical compound added to a fluid to change the properties of the fluid.

AFTERCOOLER: (1) A device which cools a gas after it has been compressed. (2) A terminal heat-transfer unit after the last stage.

AIR BLEEDER: A device used to remove air from a hydraulic system. It may be a needle valve, capillary tubing to the reservoir, or a bleed plug.

AIR CHAMBER: A chamber, usually bulb-shaped, on the suction and discharge sides of a pump. Air in the chamber acts as a cushion and prevents sudden shocks to the pump.

AIR EJECTOR: A jet pump that removes air and noncondensable gases.

AIR REGISTER: A device in the casing of a boiler which regulates the amount of air for combustion and provides a circular motion to the air.

ALIGNED SECTION: A section view in which some internal features are revolved into or out of the plane of the view.

ALLOY: Any composite metal produced by the mixing of two or more metals or elements.

ALTERNATING CURRENT (a.c.): Current that is constantly changing in value and direction at regularly recurring intervals.

AMBIENT TEMPERATURE: The temperature of the surrounding environment.

AMMETER: An instrument for measuring the rate of flow of electrical current in amperes.

AMPERE: The basic unit of electrical current.

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ANNEAL: To heat a metal and to cool it in such a manner as to toughen and soften it. Brass or copper is annealed by heating it to a cherry red and dipping it suddenly into water while hot. Iron or steel is slowly cooled from the heated condition to anneal.

ANNUNCIATOR: A device, usually electromechanical, used to indicate or transmit information. See ENGINE ORDER TELEGRAPH.

ANTIFRICTION BEARING: A bearing containing rollers or balls plus an inner and outer race. The bearing is designed to roll, thus minimizing friction.

APRON (lathe): Contains the gear train and the clutches that give controlled movement to the longitudinal and crossfeed.

ARC: (1) A flash caused by an electric current ionizing a gas or vapor. (2) A portion of the circumference of a circle.

ARMATURE: (1) The rotating part of an electric motor or generator. (2) The moving part of a relay or vibrator.

ARTICULATED CONNECTING ROD: A connecting rod assembly consisting of a master rod and a secondary rod connecting two pistons to one crank throw. Used on "V" type engine blocks.

ATMOSPHERIC PRESSURE: The pressure exerted by the atmosphere in all directions, as indicated by a barometer. Standard atmospheric pressure is considered to be 14.7 pounds per square inch, which is equivalent to 29.92 inches of mercury.

ATOMIZATION: The spraying of a liquid through a nozzle so that the liquid is broken into tiny droplets or particles.

AUTOMATIC BUS TRANSFER: See ABT.

AUTOMATIC COMBUSTION CONTROL SYSTEM (ACC): A system that automatically controls the fuel and air mixture in a boiler.

AUTOMATIC CONTROLLER: An instrument or device that operates automatically to regulate a controlled variable in response to a set point and/or input signal.

AUTOMATIC CONTROL SYSTEMS: A combination of instruments or devices arranged systematically to control a process or operation at a set point without assistance from operating personnel.

AUTOMATIC OPERATION: Operation of a control system and the process under control without assistance from the operator.

AUXILIARY MACHINERY: Any system or unit of machinery that supports the main propulsion units or helps support the ship and the crew. Example: Pump, evaporator, steering engine, air conditioning and refrigerator equipment, laundry and galley equipment, deck winch, etc.

AXIAL: In a direction parallel to the axis. Axial movement is movement parallel to the axis.

AXIS: The centerline running lengthwise.

BABBITTED: A bearing lined with a babbitt metal (containing tin, copper, and antimony).

BACK PRESSURE: (1) Resistance to the flow of exhausts (fluids and gas). (2) The pressure exerted on the exhaust side of an engine or the discharge side of a pump.

BAFFLE: A plate or structure placed in the line of flow of fluids or gases to divert the flow to obtain greater contact with heating or cooling surfaces.

BASE: A support for the main bearings in a diesel engine (more modern design). See BEDPLATE.

BDC (bottom dead center): The position of a reciprocating piston at its lowest point of travel.

BEARING: A mechanical component which supports and guides the location of another rotating or sliding member.

BEDPLATE: A support for the main bearings in large diesel engines. (Used in older designs.) See BASE.

BELL BOOK: An official record of engine orders received and answered.

BIMETALLIC: Composed of two metals with different rates of expansion which curve to a greater, or lesser, extent when subjected to temperature changes.

BLEEDER: A small cock, valve, or plug that drains off small quantities of air or fluids from a container or system.

BLOCK DIAGRAM: A diagram in which the major components of a piece of equipment or a system are represented by squares, rectangles, or other geometric figures, and the normal order of progression of a signal or current flow is represented by lines.

BLOWER: A mechanical device used to supply air under pressure to aid in scavenging.

BLUEPRINTS: Copies of mechanical or other types of technical drawings.

BOILER: Any vessel, container, or receptacle that is capable of generating steam by the internal or external application of heat. The two general classes are fire tube and water tube.

BOILER BLOW PIPING: Piping from the individual boiler blow valves to the overboard connection at the skin of the ship.

BOILER DESIGN PRESSURE: Pressure specified by the manufacturer, usually about 103% of normal steam drum operating pressure.

BOILER FEEDWATER: Deaerated water in the piping system between the deaerating feed tank and the boiler.

BOILER LOAD: The steam output demanded from a boiler, generally expressed in pounds per hour (lb/hr).

BOILER REFRACTORIES: Materials used in the boiler furnace to protect the boiler from the heat of combustion.

BOILER WATER: The water actually contained in the boiler.

BONNET: A cover used to guide and enclose the tail end of a valve spindle.

BOSCH: A fuel injection system. A German manufacturer of mechanical and electrical engine and automotive components.

BOTTOM BLOW: A procedure used to remove suspended solids and sludge from a boiler.

BOTTOM DEAD CENTER: See BDC.

BOURDON TUBE: A C-shaped hollow metal tube that is used in a gage for measuring pressures of 15 psi and above. One end of the C is welded or silver-brazed to a stationary base. Pressure on the hollow section forces the tube to try to straighten. The free end moves a needle on the gage face.

BOYLE'S LAW: The volume of any dry gas varies inversely with the applied pressure, provided the temperature remains constant.

BRAKE HORSEPOWER (bhp): A measurement of the power produced by an engine.

BRAZING: A method of joining two metals at high temperature with a molten alloy.

BREAKER POINTS: Metal contacts that open and close a circuit at timed intervals.

BRINE: (1) A highly concentrated solution of salt in water, normally associated with the overboard discharge of distilling plants. (2) Any water in which the concentration of chemical salts is higher than seawater.

BRITISH THERMAL UNIT (Btu): A unit of heat used to measure the efficiency of combustion. It is equal to the quantity of heat required to raise 1 pound of water 1°F.

BRUSH: The conducting material, usually a block of carbon, bearing against the commutator

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or sliprings through which the current flows in or out.

BULL GEAR: The largest gear in a reduction gear train—the main gear, as in a geared turbine drive.

BUS BAR: A primary power distribution point connected to the main power source.

BUSHING: A renewable lining for a hole in which a shaft, rod or similar part moves.

BUS TRANSFER: A device for selecting either of two available sources of electrical power. It may be accomplished either manually or automatically.

BUTTERFLY VALVE: A lightweight, relatively quick acting, positive shutoff valve.

BYPASS: To divert the flow of gas or liquid. Also, the line that diverts the flow.

CALIBRATE: To make adjustments to a meter or other instrument so that it will indicate correctly with respect to its inputs.

CAM: A projecting part of a shaft, wheel or other simple moving piece in a machine, shaped to give predetermined variable motion in repeating cycles to another piece against which it acts.

CAMSHAFT: A shaft with eccentric projections, called cams, designed to control the operation of valves.

CAPACITOR: The electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the dielectric.

CAPILLARY TUBE: A slender, thin-walled, small-bored tube used with remote-reading indicators.

CAPSTAN: A vertical drum or barrel operated by motors or engines which produce high torque and comparatively low speed. It is used to haul heavy lines. On combatant ships the capstan or capstan head is mounted above the wildcat on the anchor windlass. On cargo ships the horizontal equivalent, the gypsy head, is attached to cargo and anchor winches.

CARBON DIOXIDE: A colorless, odorless gas used as a fire extinguishing agent and for inflating liferafts and lifejackets.

CARBON MONOXIDE: A deadly, colorless, odorless, and tasteless gas formed by incomplete burning of hydrocarbons.

CARBON PACKING: Pressed segments of graphite used to prevent steam leakage around shafts.

CARBURETOR: An apparatus for supplying atomized and vaporized fuel mixed with air to an internal-combustion engine.

CARRIAGE: Contains the controls governing the movement of the cutting tool. The carriage is made up of two parts—saddle and apron.

CARRYOVER: (1) Boiler water entrained with the steam (by foaming or priming). (2) Particles of seawater trapped in vapor in a distilling plant and carried into the condensate.

CASING: A housing that encloses the rotating element (rotor) of a pump or turbine.

CASING THROAT: An opening in a turbine or pump casing through which the shaft protrudes.

CASUALTY: An event or series of events in progress during which equipment damage and/or personnel injury has already occurred. The nature and speed of these events are such that proper and correct procedural steps are taken to limit damage and/or personnel injury only.

CASUALTY POWER SYSTEM: Portable cables that are rigged to transmit power to vital equipment in an emergency.

CATALYST: A substance used to speed up or slow down a chemical reaction, but is itself unchanged at the end of the reaction.

CELSIUS: The temperature scale with a freezing point of 0° and a boiling point of 100°, with 100 equal divisions (degrees) between. This scale was formerly known as the centigrade scale.

CENTER REST: A device which is clamped to the ways of the lathe for supporting long shafts of small diameter while turning them.

CENTRIFUGAL FORCE: A force exerted on a rotating object in a direction outward from the center of rotation.

CETANE VALUE: A measure of the ease with which diesel fuel will ignite.

CHATTER: Machine shop equipment chatter is vibration in either the tool or the work. The vibration is set up by a weakness in the work, work support, or tool support.

CHECK VALVE: A valve which permits fluid flow in one direction, but prevents flow in the reverse direction.

CHEMICAL ENERGY: Energy stored in chemicals (fuel) and released during combustion of the chemicals.

CHILL SHOCKING: A method that uses steam and cold water to remove scale from the tubes of a distilling plant.

CHLORIDE: A compound of the chemical element chlorine with another element or radical.

CHLORINE: A heavy, greenish-yellow gas used in water purification, sewage disposal, and bleaching solutions. Poisonous in concentrated form.

CHUCK: Any of the various devices for holding work in a lathe.

CIRCUIT: An arrangement of interconnected electrical components which offers a route for current between the two points of the power source.

CIRCUIT BREAKER: An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

CIRCULATING WATER: Water circulated through a heat exchanger (condenser or cooler) to transfer heat away from an operating component.

CLARIFIER: A water tank containing baffles that slow the rate of water flow sufficiently to allow heavy particles to settle to the bottom and light particles to rise to the surface. This separation permits easy removal, thus leaving the "clarified" water. The clarifier is sometimes referred to as a settling tank or sedimentation basin.

CLOSED COOLING SYSTEM: Consisting of two entirely separate circuits–freshwater circuit and saltwater circuit.

CLUTCH: A form of coupling that connects or disconnects a driving or driven member.

COAXIAL CABLE: A transmission line consisting of two conductors concentric with and insulated from each other.

COCK: A valve which is opened or closed by a quarter turn of a disk or a tapered plug. When a plug is used, it is slotted to correspond with the ports in the valve.

COLD IRON CONDITION: An idle plant, when all services are received from an external source such as shore or tender.

COMBUSTION: The burning of fuel in a chemical process accompanied by the evolution of light and heat.

COMBUSTION AIR: The air delivered to a boiler furnace, engine, or gas turbine combustor to support burning of atomized fuel oil.

COMBUSTION CYCLE: See OTTO CYCLE and DIESEL CYCLE.

COMMUTATOR: The copper segments on the armature of a motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes.

COMPENSATING DEVICE: Mechanical or hydraulic action which prevents overcorrection of change.

COMPONENT: Individual unit, or part, of a system; also, the major units which, when suitably connected, comprise a system.

CONDENSATE: In a distilling plant, the product resulting from the condensation of steam (vapor) produced by the evaporation of seawater. Condensate may also be referred to by different names such as freshwater, freshwater distillate, or distillate.

CONDENSATE DEPRESSION: The difference between the temperature of condensate in the condenser hotwell and the saturation temperature corresponding to the vacuum maintained in the condenser.

CONDENSATION: The change from a gaseous (or vapor) state to a liquid state.

CONDENSER: A heat transfer device in which vapor is condensed to liquid.

CONDUCTANCE: The ability of a material to conduct or carry electrical or thermal energy. Electrical conductance is the reciprocal of the resistance of the material and is expressed in mhos.

CONDUCTION: Heat transfer by actual contact between substances or from molecule to molecule within a substance.

CONDUCTIVITY: The ease with which a substance transmits electricity.

CONDUCTOR: Any material suitable for carrying electric current.

CONSOLE: A panel equipped with remote manual controls and visual indicators of system performance.

CONTROL AIR SUPPLY: Clean, dry air at proper pressure for operation of pneumatic control equipment.

CONTROLLER (electrical): A device used to stop, start, and protect motors from overloads while they are running.

COOLER: Any device that removes heat. Some devices, such as oil coolers, remove heat to waste in overboard seawater discharge; other devices, such as ejector coolers, conserve heat by heating condensate for boiler feedwater.

COOLING SYSTEM: Heat removal process that uses mechanical means to remove heat to maintain the desired air temperature. The process may also result in dehumidification.

CORE (electrical): A magnetic material that affords an easy path for magnetic flux lines in a coil.

CORROSION: A gradual wearing away or alteration of metal by a chemical or electrochemical process. Essentially, it is an oxidizing process, such as the rusting of iron by the atmosphere.

COTTER, PIN, SPRING: A round split pin used to position and secure a nut on a bolt. The pin is passed through a hole in the nut and bolt. The ends of the pin opposite its head are forced apart by a screwdriver, pliers, or similar tool, thus preventing the cotter from slipping out.

COUNTERBORE: (1) The enlargement of the end of a hole for receiving and recessing the head of a screw or bolt below or flush with the surface. (2) A tapered enlargement at the end of an engine cylinder to reduce ridging by the piston's top compression ring.

COUNTERSUNK HOLE: A hole tapered or beveled around its edge to allow a rivet or bolt head or a rivet point to seat flush with or below the surface of the riveted or bolted object.

COUPLING: A device for securing together adjoining ends of piping, shafting, etc. in such a manner to permit disassembly whenever necessary.

CRANE: A machine used for hoisting and moving pieces of material or portions of structures or machines that are either too heavy to be handled by hand or cannot be handled economically by hand.

CRANKCASE: The part of an engine frame which serves as a housing for the crankshaft.

CRANKSHAFT: A shaft that changes reciprocating motion to circular motion or vice versa.

CREEP-RESISTANT ALLOY: A metal which resists the slow plastic deformation that occurs at high temperatures when the material is under constant stress.

CREST: The surface of the thread corresponding to the major diameter of an external thread and the minor diameter of an internal thread.

CRITICAL SPEED: The speed at which natural torsional vibrations of a crankshaft tend to reinforce themselves, causing vibration and potentially destructive stresses.

CROSS-CONNECT: To align systems to provide flow or exchange energy between machinery groups.

CROSS-CONNECTED PLANT: A method of operating two or more plants as one unit from a common supply.

CROSSHEAD: A mechanical device used in reciprocating engines to absorb lateral thrust which results from the action of the piston on the crankshaft.

CROSSHEAD PISTON: Elongated pistons used on old, large-bore marine engines. A composite piston with separate crown and skirt designed to absorb lateral thrust.

CROSSOVER PIPING (OR VALVES): Provides flow between port and starboard systems or systems having different purposes.

CROSS SECTION: A view of the interior of an object that is represented as being cut in two, the cut surface presenting the cross section of the object.

CROWN: The head or top of a piston.

CURRENT LIMITER: A protective device similar to a fuse, usually used in high amperage circuits.

CYCLE: An interval of time during which a sequence of a recurring succession of events is completed.

CYLINDER: A solid figure with two circular bases. A hollow tube which contains the actions of combustion gases and the piston in an internal-combustion reciprocating engine.

CYLINDER BLOCK: A rigid unit of the engine frame which supports the engine's cylinder liners and heads. A cylinder block may contain passages to allow circulation of cooling water and drilled lube oil passages.

DAMPER: A device for reducing the motion or oscillations of moving parts.

DAMPING: (1) A characteristic of a system that results in dissipation of energy and causes decay in oscillations. (2) The negative feedback of an output rate of change.

DAY TANK: A fuel tank with the capacity to operate an engine for 24 hours. Also called SERVICE TANK.

DEAERATE: Process of removing dissolved oxygen.

DEAERATING FEED TANK (DFT): A unit in the steam-water cycle used to (1) free the condensate of dissolved oxygen, (2) heat the feedwater, and (3) act as a reservoir for feedwater.

DEGREE OF SUPERHEAT: The amount by which the temperature exceeds the saturation temperature.

DEHUMIDIFICATION: The mechanical process of removing water vapor from the air.

DENSITY: The weight per unit volume of a substance.

DENTAL COUPLING: A flexible coupling assembly, consisting of a set of external/internal gear teeth, that compensates for shaft misalignment between a driver and a driven machinery component.

DEPTH: The distance from the root of a thread to the crest, measured perpendicularly to the axis.

DESIGN PRESSURE (boiler): The pressure specified by a manufacturer as a criterion in design. (In a boiler it is approximately 103% of operating pressure.)

DESIGN TEMPERATURE: The intended operating temperature of the freshwater and lube oil at the engine outlet, at some specified rate of operation. The specified rate of operation is normal load.

DESUPERHEATED STEAM: Steam from which some of the superheat has been removed.

DIAL GAGE OR INDICATOR: A precision micrometer-type instrument that indicates the reading by a needle moving across a dial face.

DIAPHRAGM: A dividing membrane or thin partition.

DIESEL CYCLE (ACTUAL): Combustion induced by compression ignition, begins on a constant-volume basis and ends on a constant-pressure basis.

DIESEL CYCLE (TRUE): Combustion induced by compression ignition, theoretically occurs at a constant pressure.

DIESEL ENGINE: An engine using the diesel or semidiesel cycle of operation; air alone is compressed and diesel fuel is injected before the end of the compression stroke. Heat of compression produces ignition.

DIFFUSER: (1) A duct of varying cross section designed to convert a high-speed gas flow into low-speed flow at an increased pressure. (2) A device that spreads a fluid out in all directions and increases fluid pressure while decreasing fluid velocity.

DIRECT CURRENT (d.c.): An electric current that flows in one direction only.

DIRECT DRIVE: One in which the drive mechanism is coupled directly to the driven member.

DIRECTIONAL CONTROL VALVE: A valve which selectively directs or prevents flow to or from desired channels. Also referred to as selector valve, control valve, or transfer valve.

DISPLACEMENT: The volume of air or fluid which can pass through a pump, motor, or cylinder in a single revolution or stroke.

DISTILLATE: The product (freshwater) resulting from the condensation of vapors produced by the evaporation of seawater.

DISTILLATION: The process of evaporating seawater, then cooling and condensing the resulting vapors. Produces freshwater from seawater by separating the salt from the water.

DISTILLING PLANTS: Units commonly called evaporators used to convert seawater into freshwater.

DOUBLE REDUCTION: A reduction gear assembly that reduces the high input rpm to a lower output rpm in two stages.

DOUBLE SUCTION IMPELLER: An impeller with suction inlet on each side.

DRAWING: (1) Illustrated plans that show fabrication and assembly details. (2) The original graphic design from which a blueprint may be made. Also called plans.

DRAWING NUMBER: An identifying number assigned to a drawing, or a series of drawings.

DRUM, WATER: A tank at the bottom of a boiler. Also called mud drum.

DUPLEX STRAINER: A strainer containing two separate elements independent of each other.

DYNAMIC PRESSURE: (1) The pressure of a fluid resulting from its motion, equal to one-half the fluid density times the fluid velocity squared. (2) In incompressible flow, dynamic pressure is the difference between total pressure and static pressure.

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ECONOMIZER: (1) A device provided in a carburetor to give the fuel-air mixture the richness required for high power. (2) A heat transfer device that uses the gases of combustion to preheat the feedwater in the boiler before it enters the steam drum. See FEED HEATER.

EDUCTOR: A jet-type pump (no moving parts) which uses a flow of water to entrain and thereby pump water.

EFFICIENCY: The ratio of output power to input power, generally expressed as a percentage.

ELASTICITY: The ability of a material to return to its original size and shape.

ELBOW-ELL: A pipe fitting that makes an angle between adjacent pipes, always 90° unless another angle is stated.

ELECTRICAL ENERGY: Energy derived from the forced induction of electrons from one atom to another.

ELECTRODE: A metallic rod (welding rod), used in electric welding, that melts when current is passed through it.

ELECTROHYDRAULIC STEERING: A system having a motor-driven hydraulic pump that creates the force needed to actuate the rams to position the ship's rudder.

ELECTROLYSIS: A chemical action that takes place between unlike metals in systems using saltwater.

ELECTROLYTE: A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET: A magnet made by passing current through a coil of wire wound on a soft iron core.

ELECTROMECHANICAL DRAWING: A special type of drawing combining electrical symbols and mechanical drawing to show the composition of equipment that combines electrical and mechanical features.

ELEMENT: (1) A substance which consists of chemically united atoms of one kind. (2) An indivisible part of a logic function or circuit. Fluidic elements are interconnected to form working circuits. (3) Parts of systems; for example, filter element, valving element, etc.

EMERGENCY: An event or series of events in progress which will cause damage to equipment unless immediate, timely, and correct procedural steps are taken.

EMULSIFIED OIL: A chemical condition of oil in which the molecules of the oil have been broken up and suspended in a foreign substance (usually water).

ENERGY: The capacity for doing work.

ENGINE: A machine which converts heat energy into mechanical energy.

ENGINE LATHE: A machine in which work is rotated about a horizontal axis and shaped by a fixed tool.

ENGINEERING LOG: A legal record of important events and data concerning the machinery of a ship.

ENGINEER'S BELL BOOK: A legal record, maintained by the throttle watch, of all ordered main engine speed changes.

ENGINE ORDER TELEGRAPH: Electromechanical device which transmits orders concerning desired direction and general speed of the engines to the engineroom. See ANNUNCIATOR.

ENGINE ORDER INDICATOR: A device on the ship's bridge which transmits orders to the engineroom for specific shaft speeds in revolutions per minute.

EPM (equivalent per million): A term used to describe the chemical concentration of dissolved material; used in reporting sample test results. It expresses the chemical equivalent unit weight of material dissolved in a million unit weights of solution. (The chemical equivalent weight of chloride is 35.5. If 35.5 pounds of chloride were dissolved in 1,000,000 pounds of water, the water would contain 1.00 epm chloride).

EQUILIBRIUM: The state of balance between opposing forces or actions.

EVAPORATION: The action that takes place when a liquid changes to a vapor or gas.

EVAPORATOR: A distilling device to produce freshwater from seawater.

EXPANSION JOINT: (1) A junction in a piping system which allows for expansion and contraction. (2) A term applied to a joint which permits linear movement to take up the expansion and contraction due to changing temperature of ship movement.

EXPANSION TANK: Provides for expansion, overflow, and replenishment of cooling water in an engine.

EXPLODED VIEW: A pictorial view of a device in a state of disassembly, showing the appearance and interrelationship of parts.

EXTERNAL THREAD: A thread on the outside of a member. Example: A thread of a bolt.

FAHRENHEIT: The temperature scale using the freezing point as 32 and the boiling point as 212, with 180 equal divisions (degrees) between.

FAIL: (1) The loss of control signal or power to a component. (2) The breakage or breakdown of a component or component part.

FATIGUE: The tendency of a material to break under repeated strain.

FEEDBACK: (1) A transfer of energy from the output circuit of a device back to its input. (2) Information about a process output which is communicated to the process input.

FEEDER: An electrical conductor or group of conductors between different generating or distributing units of a power system.

FEED HEATER: A heat transfer device that heats the feedwater before it goes to the boiler.

FEEDWATER: Water that meets the requirements of *NAVSHIPS' Technical Manual* Chapter 220 (9560) for use in a boiler.

FERROUS METAL: Metal with a high iron content.

FIELD WINDING: The coil used to provide the magnetizing force in motors and generators.

FILTER: A device through which gas or liquid is passed; dirt, dust, and other impurities are removed by the separating action.

FIRELINE: Section of piping and hose on discharge side of a proportioner leading to a fire location.

FIRE MAIN: The saltwater line that provides firefighting and flushing water throughout the ship.

FIRE TUBE BOILER: Boilers in which the gases of combustion pass through the tubes and heat the water surrounding them.

FLASHPOINT: The temperature at which a substance, such as an oil, will give off a vapor that will flash or burn momentarily when ignited.

FLEXIBLE COUPLING: A coupling that transmits rotary motion from one shaft to another while compensating for minor misalignment between the two units.

FLOOR PLATES: The removable deck plating of a fireroom or engineroom aboard ship. Also called deck plates.

FLOWMETER: An instrument used to measure quantity or the flow rate of a fluid motion.

FLUID: A substance capable of flowing or conforming to the shape of its container (a liquid or gas or mixture thereof).

FLYBALL (governor): Weights which move and assume positions in accordance with the speed of rotation.

FLYWHEEL: A heavy wheel attached to the crankshaft. It stores up energy during the power event and releases it during the remaining events of the operating cycle.

FOAM NOZZLE: A nozzle designed to entrain air and mix it with water and foam liquid to produce a foam blanket.

FOOT-POUND: (1) The amount of work accomplished when a force of 1 pound produces a displacement of 1 foot. (2) The amount of torque produced by 1 pound of effort applied at a radius of 1 foot.

FORCE: The action of one body on another tending to change the state of motion of the body acted upon. Force is usually expressed in pounds.

FORCE-BALANCE: An arrangement of control system components using a mechanical force as the feedback signal. The feedback applied force must "null" the forces acting on a balanced mechanism.

FORCED FEED LUBRICATION: A lubrication system that uses a pump to maintain a constant pressure.

FREE FLOW: Flow which encounters negligible resistance.

FREQUENCY: The number of complete cycles per second (hertz) existing in any form of wave motion.

FRESHWATER: Water of relatively low dissolved solids content as compared to seawater. There are two types of shipboard freshwater: feedwater (the low-pressure drains of the steam generator condensate system) and potable water (supplied from either a shore water source or a shipboard distilling plant).

FRESHWATER SYSTEM: A piping system which supplies freshwater throughout the ship.

FRICTION: The action of one body or substance rubbing against another, such as fluid flowing against the walls of a pipe; the resistance to motion caused by this rubbing.

FRICTION PRESSURE DROP: The decrease in the pressure of a fluid flowing through a passage attributable to the friction between the fluid and the passage walls.

FUEL OIL: Navy Distillate Fuel MIL-F-24397, Diesel Fuel Marine MIL-F-16884, JP5 MIL-T-5624, or Navy Special Fuel Oil MIL-F-859.

FUEL OIL SERVICE TANKS: Tanks from which the fuel oil service pumps take suction for supplying diesel fuel oil to the engine. See DAY TANKS.

FUSE: A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAGE GLASS: A device for indicating the liquid level in a tank.

GAGE PRESSURE: Pressure above atmospheric pressure.

GALVANIZING: The process of coating one metal with another, ordinarily applied to the coating of iron or steel with zinc. The chief purpose of galvanizing is to prevent corrosion.

GAS: The form of matter which has neither a definite shape nor a definite volume.

GAS FREE: A term used to describe a space that has been tested and its atmosphere found safe for human occupation and for hot work (welding and cutting).

GASKET(S): (1) A class of material which provides a seal between two stationary parts. (2) Packing materials, by which air, water, oil, or steam tightness is secured in such places as on doors, hatches, cylinders, manhole covers, or in valves, between the flanges of pipes, etc. Such materials as rubber, canvas, asbestos, paper,

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sheet lead and copper, soft iron, and commercial products are extensively used.

GEARING: A term applied to wheels which have teeth that mesh, engage, or gear with similar teeth or other wheels in such manner that motion given one wheel will be imparted to the other.

GENERATOR: A machine that converts mechanical energy into electrical energy.

GLAND SEALING: Water piped to a pump casing stuffing box to maintain a seal against air entering the pump casing.

GOVERNOR: A speed-sensitive device designed to control or limit the speed of the engine.

GRAPHITE: A crystalline form of carbon having a slippery feel and black color with metallic luster. Used for a lubricant.

GRAVITY HEAD: A supply of fluid above the suction level of a pump. Also called "statichead."

GROUND PLUG: A three-pronged electrical plug used to ground portable tools to the ship's structure. It is a safety device which always must be checked prior to your using portable tools.

HAGEVAP SOLUTION: A chemical compound used in distilling plants to prevent the formation of scale. Now called PD-8.

HALIDE LEAK DETECTOR: A device that is used to locate leaks in refrigeration systems.

HANDHOLE: An opening large enough for the hand and arm to enter areas, such as the engine, for making slight repairs and for inspection purposes.

HARDENING: The treatment or heating and cooling (quenching) of metal to harden the surface.

HARDNESS: A quality exhibited by water containing various dissolved salts, principally calcium and magnesium. Hard water can deposit a heat transfer resistant scale on the heat exchanger surface.

HEAD: (1) A separate unit from the engine cylinder block designed to seal the cylinder at the combustion end. (2) The pressure or energy content of a hydraulic system, expressed in the height of a column of water in feet.

HEAT: A thermal form of energy.

HEAT EXCHANGER: Any device that is designed to allow the transfer of heat from one fluid (liquid or gas) to another.

HEATING SURFACE: The exposed surface of a heating unit in a heat exchanger which is directly exposed to the heat of the flue gases.

HEATING SYSTEM: A system for adding heat to maintain the desired air temperature, as distinguished from heat added incidentally or unavoidably.

HELICAL: A spiraling shape such as that made by a coil spring.

HELIX: The curve formed on any cylinder by a straight line in a plane that is wrapped around the cylinder with a forward progression.

HELM: (1) The term applied to the tiller, wheel, or steering gear, and also the rudder. (2) Mechanical device used to turn the rudder; usually a wheel aboard ship, a lever (tiller) in boats.

HERTZ: The measurement of frequencies in cycles per second, 1 hertz being equal to 1 cycle per second.

HORSEPOWER (hp): A unit for measuring the power of motors or engines, equal to a rate of 33,000 foot-pounds per minute. The force required to raise 33,000 pounds at the rate of 1 foot per minute.

HOT WELL: Reservoir attached to the bottom of a condenser for collecting condensate.

HUMIDITY: The vapor content of the atmosphere. Humidity can vary depending on air temperature; the higher the temperature, the more vapor the air can hold.

HUNTING: A rhythmic variation of speed which can be eliminated by blocking the fuel supply manually or with load limit but which will reappear when returned to governor control.

HYDRAULICS: That branch of mechanics or engineering that deals with the action or use of liquids forced through tubes and orifices under pressure to operate various mechanisms.

HYDROCARBON: Chemical compound of hydrogen and carbon. All petroleum fuels are composed of hydrocarbons.

HYDROGEN: A highly explosive, light, invisible, nonpoisonous gas. It is produced in small quantities when batteries are charged.

HYDROMETER: An instrument used to determine the specific gravities of liquids.

HYDROSTATIC: Static (nonmoving) pressure generated by pressurizing liquid.

HYDROSTATIC TEST: A test using pressurized water to detect leaks in a closed system.

HYGROMETER: An instrument for measuring humidity.

IGNITION, COMPRESSION: When the heat generated by compression in an internal-combustion engine ignites the fuel (as in a diesel engine).

IGNITION, SPARK: When the mixture of air and fuel in an internal-combustion engine is ignited by an electric spark (as in a gasoline engine).

IGNITION TEMPERATURE: The minimum temperature to which a fuel must be heated to cause self-sustained combustion.

IMPEDANCE: The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

IMPELLER: An encased, rotating element provided with vanes which draw in fluid at the center and expel it at a high velocity at the outer edge.

IMPINGEMENT: The striking or hitting against an object with a clash or sharp collision, as air impinging upon the rotor of a turbine or motor.

IMPULSE LINES: Piping that connects a sensing element to the point at which it is desired to sense pressure, flow, temperature, etc.

INDICATORS: Panel-mounted pressure gages.

INDIRECT DRIVE: A drive mechanism coupled to the driven member by gears or belts.

INDUCTION: The act or process of producing voltages by the relative motion of a magnetic field across a conductor.

INERT: Inactive. Applied to gases that will not burn or support combustion.

INERTIA: The tendency of a body at rest to remain at rest, and a body in motion to continue to move at a constant speed along a straight line, unless the body is acted upon in either case by an unbalanced force.

INHIBITOR: Any substance which retards or prevents such chemical reactions as corrosion or oxidation.

INJECTION NOZZLE: A device which protrudes into the combustion chamber and delivers fuel to the cylinder.

INJECTION SYSTEM: A system designed to deliver fuel to the cylinder at the proper time and in the proper quantity under various engine loads and speeds.

IN-LINE ENGINE: An engine in which the cylinders are arranged in one straight line.

IN PHASE: Applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

INPUT SIGNAL: A pressure or flow of fluid which is directed into an input port to control an element or logic function.

INSULATION: A material used to retard heat transfer. A dielectric material which prevents the flow of electricity from an electric component.

INTAKE SYSTEM: Combination of components designed to supply air required for combustion.

INTEGRAL: Essential to completeness, as an integral part. (The valve stem is an integral part of the valve.)

INTERCOOLER: A device which cools a gas between the compression stages of a multiple stage compressor.

INTERFACE: Surface or area between abutting parts usually of different materials.

INTERNAL THREAD: A thread on the inside of a member. Example: The thread inside a nut.

INVERSELY: Inverted or reversed in position or relationship.

INVERSE PROPORTION: The relation that exists between two quantities when an increase in one of them produces a corresponding decrease in the other.

ISOCHRONOUS GOVERNOR: Maintaining the speed of the engine truly constant, regardless of the load.

ISOMETRIC DRAWING: A type of pictorial drawing. See ISOMETRIC PROJECTION.

ISOMETRIC PROJECTION: A set of three or more views of an object that appears rotated, giving the appearance of viewing the object from one corner. All lines are shown in their true length, but angles are not accurately represented.

JACKBOX: Receptacle, usually secured to a bulkhead, in which telephone jacks are mounted.

JACKET: An outer case such as a water jacket or an insulative covering.

JACKET WATER: Water used as a coolant in the cooling system of an engine (usually chemically treated distilled water).

JACKING: Mechanically rotating an engine or reduction gear at very low speed.

JAM NUT: A second nut used on a bolt or stud to lock the holding nut. See LOCK NUT.

JOB ORDER: An order issued by a repair activity to its own subdivision to perform a repair job in response to a work request.

JOURNAL: Serves as the point of support and center of rotation for the shaft. That part of a shaft that is prepared to accept a bearing (connecting rod, main bearing).

JUMPER: Any connecting pipe, hose, or wire normally used in emergencies aboard ship to bypass damaged sections of a pipe, a hose, or a wire. See BYPASS.

JURY RIG: Any makeshift device or apparatus.

KELVIN SCALE: The temperature scale using absolute zero as the zero point and divisions that are the same size as Celsius degrees.

KEY: A small wedge or rectangular piece of metal inserted in a slot or groove between a shaft and a hub to prevent slippage.

KEYWAY: A slot cut in a shaft, pulley hub, wheel hub, etc. A square key is placed in the slot and engages a similar keyway in the mating piece. The key prevents slippage between the two parts.

KILO: A prefix meaning 1,000.

KINETIC ENERGY: The energy which a substance has while it is in motion.

LABYRINTH PACKING: A soft metal ring or rings arranged inside a casing throat in such a manner that the inside diametrical edges will form a series of seals along the surface of the rotating shaft. The edges fit either close to the surface of the shaft or in grooves machined in the shaft.

LAGGING: (1) A protective and confining cover placed over insulating material. (2) A term applied to the insulating material that is fitted on the outside of engine exhaust, piping, etc.

LAMBERT SEAL: The hydraulic equivalent of labyrinth packing.

LAP: To work two surfaces together with abrasives until a very close fit is produced; to polish.

LASH: The clearance or play between adjacent movable mechanical parts. See VALVE LASH.

LATENT HEAT: Heat that is given off or absorbed by a substance while it is changing its state.

LATENT HEAT OF CONDENSATION: The amount of heat (energy) required to change the state of a substance from a vapor to a liquid without a change in temperature.

LATENT HEAT OF VAPORIZATION: The amount of heat (energy) required to change the state of a substance from a liquid to a vapor without a change in temperature.

LEAD: (1) The distance a screw thread advances in one turn, measured parallel to the axis. On a single-thread screw the lead and the pitch are identical; on a double-thread screw the lead is twice the pitch; on a triple-thread screw the lead is three times the pitch. (2) A wire or connection.

LIFT CHECK VALVE: A valve having a guide-mounted, spring-loaded disk wherein a liquid exerting pressure on the bottom of the disk will lift the disk and pass through. Pressure against the top of the disk shuts the disk and ensures only one direction of flow.

LIGHT OFF: Start. Literally, "to start a fire in," as in "light off a boiler."

LIMIT SWITCH: A switch that is actuated by the mechanical motion of an element.

LIQUID: A form of matter which has a definite volume but takes the shape of its container.

LOAD: (1) External resistance overcome by a prime mover. (2) The power that is being delivered by a generator.

LOADING: The act of transferring energy into or out of a system.

LOCAL MANUAL OPERATION: Direct manual positioning of a control valve or power operator by means of a handwheel or lever.

LOCKED TRAIN: A gear arrangement that has each high-speed (prime mover) pinion "locked" between two primary gears which cancel the tooth loading on the pinion bearings.

LOCK NUT: (1) A thin nut that is turned down over the regular nut on a bolt to lock the regular nut against turning off. See JAM NUT. (2) A thin nut placed on a pipe to hold packing at a joint or used on both sides of a bulkhead through which a pipe passes to secure tightness.

LOG: (1) A ship's speedometer. (2) The act of a ship in making a certain speed, as "The ship logged 20 knots." (3) Book or ledger in which the watch officer records data or events that occurred during the watch.

LOG BOOK: Any chronological record of events, such as engineering watch log.

LOG ROOM: Engineer's office aboard ship.

LOOP SEAL: A vertical U-bend in drain piping in which a water level is maintained to create an airtight seal.

LUBE OIL PURIFIER: A unit that removes water and sediment from lubricating oil by centrifugal force.

LUBRICANT: Any material, usually of a petroleum nature, such as grease, oil, etc. that is placed between two moving parts in an effort to reduce friction.

LUG: An earlike projection that is frequently split as the clamping lug on the tailstock of a lathe.

MACHINABILITY: The ease with which a metal may be turned, planed, milled, or otherwise shaped.

MACHINE FINISH: Operation of turning or cutting an amount of stock from the surface of metal to produce a finished surface.

MAGNETIC FIELD: The space in which a magnetic force exists.

MAGNETO: A generator which produces alternating current and has a permanent magnet as its field.

MAIN CONDENSER: A heat exchanger that converts exhaust steam to feedwater.

MAIN DRAIN SYSTEM: System used for pumping bilges; consists of pumps and associated piping.

MAIN INJECTION (SCOOP INJECTION): An opening in the skin of a ship designed to deliver cooling water to the main condenser by the forward motion of the ship.

MAJOR DIAMETER: The largest diameter of an internal or external thread.

MALLEABILITY: That property of a material which enables it to be stamped, hammered, or rolled into thin sheets.

MANIFOLD: (1) A fitting or header that receives exhaust gases from several cylinders. (2) A fitting that has several inlets or outlets to carry liquids or gases.

MAXIMUM OPERATING PRESSURE: The highest pressure that can exist in a system or subsystem under normal operating conditions.

MAXIMUM SYSTEM PRESSURE: The highest pressure that can exist in a system or subsystem during any condition.

MECHANICAL ADVANTAGE (MA): The advantage (leverage) gained by the use of devices such as a wheel to open a large valve, chain falls and block and tackle to lift heavy weights, and wrenches to tighten nuts on bolts.

MECHANICAL CLEANING: A method of cleaning the firesides of boilers by scraping and wirebrushing.

MECHANICAL CYCLE: The number of piston strokes occurring during any one series or events. (Example: 2-stroke or 4-stroke cycle.)

MECHANICAL DRAWING: Scale drawings of mechanical objects. See DRAWING.

MECHANICAL ENERGY: Energy derived from mechanical force or impact.

MEGGER: A test instrument used to measure insulation resistance and other high resistances. It is a portable hand-operated d.c. generator used as an ohmmeter.

MEGOHM: One million ohms.

METALLURGY: (1) Science dealing with the constitution, structure, and properties of metals and alloys. (2) The processes by which metals and alloys are obtained from ore and adapted to use.

METERING: Accurate measuring of the fuel for the same fuel setting where exactly the same quantity of fuel will be delivered to each cylinder for each power stroke of the engine.

MHO: The unit of conductance; the reciprocal of an ohm.

MICRO: One millionth.

MICROMHO: Electrical unit used with salinity indicators for measuring the conductivity of water.

MILLI: A prefix meaning one-thousandth.

MONITORING POINT: The physical location at which any indicating device displays the value of a parameter at some control station. See PARAMETER.

MOTOR: (1) A rotating machine that transforms electrical energy into mechanical energy. (2) An actuator which converts fluid power to rotary mechanical force and motion.

MOTOR CONTROLLER: A device or group of devices that governs, in some predetermined manner, the operation of the motor to which it is connected.

MOTOR GENERATOR SET: A machine consisting of a motor mechanically coupled to a generator and usually mounted on the same base.

NAVY BOILER COMPOUND: A powdered chemical mixture used in combination with other chemicals for engine and boiler water treatment.

NAVY DISTILLATE FUEL (ND): Boiler fuel used in steam-powered ships; a fuel of the middle to high distillation range.

NAVY MARINE DIESEL FUEL (DFM): The approved fuel for Navy diesel engines and gas turbines.

NEEDLE VALVE: Type of valve with rod-shaped, needle-pointed valve body which works into a valve seat so shaped that the needle point fits into it and closes the passage. Suitable for precise control of flow.

NEGATIVE CHARGE: The electrical charge carried by a body which has an excess of electrons.

NEOPRENE: A synthetic rubber highly resistant to oil, light, heat, and oxidation.

NIGHT ORDER BOOK: A notebook containing standing and special instructions from the engineering officer to the engineering officers of the night watches.

NIPPLE: A piece of pipe that has an outside thread at both ends for use in making pipe connections. Various names are applied to different lengths, as close, short, long, etc.

NITROGEN: An inert gas which will not support life or combustion. Used in weapon recoil systems and other spaces that require an inert atmosphere.

NOMINAL OPERATING PRESSURE: The approximate pressure at which an essentially constant-pressure system operates. This pressure is used for the system's basic pressure identification.

NONFERROUS METAL: Metal that is composed primarily of a metallic element, or elements other than iron.

NORMALIZE: To heat steel to a temperature slightly above its critical point and then allow it to cool slowly in air.

NOZZLE: A taper or constriction used to speed up or direct the flow of gas or liquid.

NOZZLE AREA: Smallest opening (area) of a nozzle that is at a right angle to the direction of flow.

OCCUPATIONAL STANDARDS: Requirements that describe the work of each Navy rating.

OFFICER OF THE WATCH (OOW): Officer on duty in the engineering spaces.

OFFSET SECTION: A section view of two or more planes in an object to show features that do not lie in the same plane.

OHM: The unit of electrical resistance.

OHMMETER: An instrument for directly measuring resistance in ohms.

OIL KING: A petty officer who receives, transfers, discharges, and tests fuel oil and maintains fuel oil records.

OIL POLLUTION ACTS: The Oil Pollution Act of 1924 (as amended) and the Oil Polution

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Act of 1961 (as amended) prohibit the overboard discharge of oil or water which contains oil, in port, in any sea area within 50 miles of land, and in special prohibited zones.

OIL STRAINER: A strainer placed at the inlet end of the oil pump to prevent dirt and other particles from getting into moving parts.

OILTIGHT: Having the property of resisting the passage of oil.

ONBOARD PLANS: See SHIP'S PLANS.

OPERATING CHARACTERISTICS: The combination of a parameter and its set points. See PARAMETER.

OPERATING PRESSURE: The constant pressure at which a component is designed to operate in service.

OPERATING TEMPERATURE: The actual temperature of a component during operation.

OPERATION (AUTOMATIC): The regulation of a process by a controlling system without manual intervention.

OPERATION (LOCAL-MANUAL): Positioning of a final control element by attending personnel from the element's manual control stations.

ORIFICE: A circular opening in a flow passage which acts as a flow restriction.

OSCILLATION: A backward and forward motion; a vibration.

OTTO COMBUSTION CYCLE: Combustion induced by spark ignition occurring at constant volume. The basic combustion cycle of a gasoline engine.

OUTPUT SIGNAL: The pressure or flow of fluid leaving the output port of a fluidic device.

OVERHAUL: To inspect, repair, and put in proper condition for operation.

OVERLOAD: A load greater than the rated load of an engine or electrical device.

OXIDATION: The process of various elements and compounds combining with oxygen. The corrosion of metals is generally a form of oxidation; rust on iron, for example, is iron oxide or oxidation.

OXYGEN-FREE FEEDWATER: Water from which dissolved oxygen has been removed.

PACKING: A class of seal that provides a seal between two parts of a unit which move in relation to each other.

PANT, PANTING: A series of pulsations caused by minor, recurrent explosions in the firebox of a ship's boiler. Usually caused by a shortage of air.

PARALLEL CIRCUIT: An electrical circuit with two or more resistance or impedance units connected to split the current flow through both units at the same time.

PARALLEL OPERATION: Two or more units operating simultaneously and connected so their output forms a common supply, as opposed to series or independent operation.

PARAMETER: A variable such as temperature, pressure, flow rate, voltage, current, frequency, etc. which may be indicated, monitored, checked or sensed in any way during operation or testing.

PARTIAL SECTION: A sectional view consisting of less than a half-section. Used to show the internal structure of a small portion of an object. Also known as broken section.

PARTICULATE: Minute particles or quantities of solid matter resulting from incomplete combustion. Carbon, sulphur, ash, and various other compounds are all referred to as particulate, either collectively or individually, when discharged into a flue or into the atmosphere.

PERIPHERY: (1) The curved line which forms the boundary of a circle (circumference), ellipse, or similar figure. (2) The outside surface, especially that of a rounded object or body.

pH: A chemistry term that denotes the degree of acidity or alkalinity of a solution. The pH of water solution may have any value between 0 and 14. A solution with a pH of 7 is neutral. Above 7, it is alkaline; below 7, it is acidic.

PHANTOM VIEW: A view showing the alternate position of a movable object, using a broken line convention.

PHASE: An impulse of alternating current. The number of phases depends on the generator windings. Most large generators produce a 3-phase current which must be carried on at least three wires.

PHYSICAL CHANGE: A change which does not alter the composition of the molecules of a substance, such as from gas to liquid.

PICTORIAL DRAWING: A drawing which gives the real appearance of an object, showing general location, function, and appearance of parts and assemblies.

PILOT VALVE: A small valve disk and seat, usually located within a larger disk, which controls the operation of another valve or system.

PILOT VALVE (governor): A hydraulic control valve which regulates hydraulic pressure to a piston and cylinder.

PINION: A gear that meshes with a larger gear.

PIPE: A tube or hollow body for conducting a liquid or gas. Dimensions of a pipe are designated by nominal (approximate) outside diameter (OD) and wall thickness.

PIPING: An assembly of pipe or tubing, valves, and fittings that forms the transferring part of a system.

PISTON: A principal part of the power transmitting assembly of a reciprocating pump or internal-combustion engine. It is usually cylindrical in shape and slides up and down in a hollow cylinder. In an engine it converts gas pressure to mechanical force.

PISTON RING: A springy split metal ring for sealing the gap between a piston and the cylinder wall.

PITCH: A term applied to (1) the distance a propeller will advance during one revolution; (2) the distance between the centers of the teeth of a gear wheel; (3) the axial advance of one convolution of the thread on a screw; (4) the spacing of rivets, etc.

PITTING: The localized corrosion of iron and steel in spots, usually caused by irregularities in surface finish and resulting in small indentations or pits.

PLAN VIEW: A view of an object or area as it would appear from directly above.

PLUG-COCK: A valve that has a rotating plug which is drilled for the passage of fluid.

PLUNGER: See RAM TYPE CYLINDER.

PNEUMATIC: Driven, or operated, by air pressure.

PNEUMATICS: That branch of physics pertaining to the pressure and flow of gases.

PNEUMERCATOR: A type of manometer that measures the volume of liquid in tanks.

POSITIVE CHARGE: The electrical charge carried by a body which has become deficient in electrons.

POLE: (1) The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet. (2) An electrode of a battery.

POTABLE WATER: Water that is suitable for drinking. The potable water system supplies scuttlebutts, sinks, showers, sculleries, and galleys, as well as provides makeup water for various freshwater cooling systems.

POTENTIAL: The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIAL ENERGY: (1) Energy at rest; stored energy. (2) The energy a substance has because of its position, its condition, or its chemical composition.

POWER: The rate of doing work or the rate of expending energy. The unit of electrical power is the watt; the unit of mechanical power is horsepower.

PPM (parts per million): Concentration of the number of parts of a substance dissolved in a million parts of another substance. Used to measure the salt content of water. If 1 pound of sea salt were dissolved in 1,000,000 pounds of water, the sea salt concentration would be 1.00 ppm.

PRESSURE: The amount of force distributed over each unit of area. Pressure is expressed in pounds per square inch (psi), atmospheric units, or kilograms per square centimeter, inches of mercury, and other ways.

PRESSURE DIFFERENTIAL: The difference in pressure between any two points of a system or a component.

PRESSURE RELIEF VALVE: A valve designed to open when pressure in the system exceeds a certain limit.

PRESSURE SWITCH: An electrical switch operated by the increase and decrease of pressure.

PRESSURE-TIME FUEL SYSTEM: A system in which fuel is injected into the cylinders at a specific pressure in separately timed events.

PRIMARY SENSING ELEMENT: The control component that transforms energy from the controlled medium to produce a signal which is a function of the value of the controlled variable.

PRIME MOVER: (1) The source of motion—as a diesel engine. (2) The source of mechanical power used to drive a pump or compressor. (3) The source of mechanical power used to drive the rotor of a generator.

PRIMING: To fill, load, put in working order (filling a fuel system with fuel, a pump with water).

PROMPTNESS: The time it takes a governor to move the fuel control from a no load position to a full load position.

PROPELLER: A propulsive device consisting of a boss or hub carrying two or more radial blades. Also called a SCREW.

PROPELLER ARCH: The arched section of the stern frame above the propeller.

PROPELLER GUARD: A framework fitted somewhat below the deck line on narrow, high-speed vessels with large screws, designed to overhang and thus protect the tips of the propeller blades.

PROPELLER THRUST: The effort delivered by a propeller in pushing a vessel ahead.

PROPULSION PLANT: The entire propulsion plant or system, including prime movers and those auxiliaries essential to their operation.

PSYCHROMETER: A form of hygrometer consisting of a wet and a dry bulb thermometer.

PULSATION: A rhythmical throbbing or vibrating.

PUMP: (1) A device which converts mechanical energy into fluid energy. (2) A device that raises, transfers, or compresses fluids or gases.

PUMP CAPACITY: The amount of fluid a pump can move in a given period of time, usually stated in gallons per minute (gpm).

PUMP RISER: The section of piping from the pump discharge valve to the piping main.

PURGE: To make free of an unwanted substance. (As to bleed air out of a fuel system).

PURPLE-K-POWDER (PKP): A purple powder composed of potassium bicarbonate that is used on class B fires. Can be used on class C fires; however, CO_2 is a better agent for such electrical fires because it leaves no residue.

PYROMETER: A device for measuring high temperatures such as the exhaust temperature of an internal-combustion engine.

QUALS MANUAL: See *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068 with changes.

QUARTERMAN: An underforeman; a term generally restricted to Navy yards.

RACE (bearing): The inner or outer ring that provides a contact surface for the balls or rollers in a bearing.

RADIAL BEARINGS: Bearings designed to carry loads applied in a plant perpendicular to the axis of the shaft and used to prevent movement in a radial direction.

RADIAL THRUST BEARINGS: Bearings designed to carry a combination of radial and thrust loads. The loads are applied both radially and axially with a resultant angular component.

RADIANT HEAT: Heat transferred without physical contact between the emitting region and the receiving region.

RADIUS: A straight line from the center of a circle or sphere to its circumference or surface.

RAM TYPE CYLINDER: A fluidic actuating cylinder in which the cross-sectional area of the piston rod is more than one-half the cross-sectional area of the movable piston-like element. The piston used is also referred to as a PLUNGER.

RATE ACTION: That action of a control system component whose output is proportional to the rate of change in its input for slowly changing signals and proportional to the input for rapidly changing signals.

RATIO: The value obtained by dividing one number by another, indicating their relative proportions.

RAW WATER: Untreated water used for cooling.

REACH ROD: A length of pipe or bar stock used as extension on valve stems.

RECEIVER: (1) A container in which compressed gas is stored to supply pneumatic power. (2) A reservoir for pressure refrigerant.

RECEIVER INDICATOR: Pressure-sensitive instrument indicating the loading pressure signals in percentage.

RECIPROCATING: Moving back and forth, as a piston reciprocating in a cylinder.

REDUCER: (1) Any coupling or fitting that connects a large opening to a smaller pipe or hose. (2) A device that reduces pressure in a fluid (gas or liquid) system.

REDUCING STATION: An assembly consisting of a reducing valve, isolation valves, and bypass valves for the reducer.

REDUCING VALVES: Automatic valves that provide a steady pressure lower than the supply pressure.

REDUCTION GEAR: An arrangement of shafts and gears such that the number of revolutions of the output shaft is less than that of the input shaft—generally used between a prime mover and the propeller shaft.

REEFER: (1) A provision cargo ship or a refrigerated compartment. (2) An authorized abbreviation for refrigerator.

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REFRIGERANT 12 (R-12): A nonpoisonous gas used in air conditioning and refrigeration systems. One of a series of fluorocarbon refrigerants.

REFRIGERATION TON: Unit of measure for the amount of heat removed, equal to 12,000 Btu per hour.

REGULATOR (gas): An instrument that controls the flow of gases from compressed gas cylinders.

RELATIVE HUMIDITY: The ratio of the weight of water vapor in a quantity of air to the weight of water vapor which that quantity of air would hold if saturated at the existing temperature. Usually expressed as a percentage; for example, if air is holding half the moisture it is capable of holding at the existing temperature, the relative humidity is 50%.

RELAY: A magnetically operated switch that makes and breaks the flow of current in a circuit.

RELIEF VALVE: A pressure control valve used to limit system pressure.

REMOTE OPERATING GEAR: Flexible cables or shafts attached to valve wheels so the valves can be operated from another compartment.

RESERVOIR: A container which serves primarily as a supply source of the liquid for a hydraulic system.

RESISTANCE: The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RESPONSE TIME: The time lag between a signal input and the resulting change of output.

RESTRICTION: A reduced cross-sectional area in a line or passage which reduces the rate of flow.

RETURN LINE: A line used for returning fluid to the reservoir or atmosphere.

RHEOSTAT: A variable resistor. Similar in function and construction to a potentiometer.

RISER: A vertical pipe leading off a large one; for example, fire main line.

ROCKER ARM: Part of the valve actuating mechanism of a reciprocating engine.

ROOT: The surface of the thread corresponding to the minor diameter of an external thread and the major diameter of an internal thread.

ROOT VALVE: A valve located where a branch line comes off the main line.

ROTOR: The rotating element of a motor, pump, or turbine.

RUDDER STOCK: A vertical shaft that has a rudder attached to its lower end and a yoke, quadrant, or tiller fitted to its upper portion by which it may be turned.

RUDDER STOPS: Fittings attached to the ship structure or to shoulders on the rudder post to limit the swing of the rudder.

SAFETY VALVE: An automatic, quick opening and closing valve which has a reset pressure lower than the lift pressure.

SALINE/SALINITY: (1) Constituting, or characteristic of salt. (2) Relative salt content of water.

SALINOMETER: A hydrometer that measures the concentration of salt in a solution.

SATURATED AIR: Air that attains the maximum amount of moisture it can hold at a specified temperature.

SATURATED STEAM: Steam at the saturation temperature.

SATURATION PRESSURE: The pressure corresponding to the saturation temperature.

SATURATION TEMPERATURE: The temperature at which a liquid boils under a given pressure. For a given pressure there is a corresponding saturation temperature.

SAYBOLT VISCOSIMETER: An instrument that determines the fluidity or viscosity (resistance to flow) of an oil.

SCALE: Undesirable deposit, mostly calcium sulfate, which forms in the tubes of boilers.

SCAVENGING AIR: Increased amount of air available as a result of blower action used to fill an engine cylinder with a fresh charge of air and, during the process, to aid in clearing the cylinder of the gases of combustion.

SCHEMATIC DIAGRAM: A diagram using graphic symbols to show how a circuit functions electrically.

SCREW: See PROPELLER.

SEA CHEST: An arrangement for supplying seawater to engines, condensers, and pumps and for discharging waste water from the ship to the sea. It is a cast fitting or a built-up structure located below the waterline of the vessel and having means for attachment of the piping. Suction sea chests are fitted with strainers or gratings.

SEA COCK, SEA CONNECTION: A sea valve secured to the plating of the vessel below the waterline for use in flooding tanks, magazines, etc. to supply water to pumps and for similar purposes.

SEAWATER: The water in the sea. Seawater is an aqueous solution of various minerals and salts (chlorides). In suspension also, but not dissolved in the water, may be various types of vegetable and animal growths, including in many cases bacteria and organisms harmful or actually dangerous to health.

SECTION: A view showing internal features as if the viewed object has been cut or sectioned.

SEDIMENT: An accumulation of matter which settles to the bottom of a liquid.

SENSIBLE HEAT: Heat that is given off or absorbed by a substance without changing its state.

SENSING POINT: (1) The physical and/or functional point in a system at which a signal may be detected and monitored or may cause some automatic operation to result. (2) Where parameters are determined.

SENSITIVITY: The change in speed required before the governor will make a corrective movement.

SENSOR: A component that senses physical variables and produces a signal to be observed or to actuate other elements in a control system. Temperature, sound, pressure and position sensors are examples.

SENTINEL VALVE: A relief valve designed to emit an audible sound; does not have substantial pressure-relieving capacity.

SEPARATOR: A trap for removing oil and water from compressed gas before it can collect in the lines or interfere with the efficient operation of pneumatic systems.

SERVICE TANKS: Tanks in which fluids for use in the service systems are stored. Also DAY TANK.

SERVO: A device used to convert a small movement into a greater movement or force.

SET POINT: The level or value at which a controlled variable is to be maintained.

SETSCREW: A machine screw with a slotted, allen, or square head used to hold a part in place.

SHAFT ALLEY: A watertight passage, housing the propeller shafting from the engineroom to the bulkhead at which the stern tube commences.

SHAFT/SHAFTING: The cylindrical forging, solid or tubular, used for transmission of rotary motion from the source of power, the engine, to the propellers.

SHIM: Thin layer of metal or other material used to true up a machine or inserted in bearings to permit adjustment after wear of the bearing.

SHIP'S PLANS: A set of drawings of all significant construction features and equipment of a ship, as needed to operate and maintain the ship. Also called ONBOARD PLANS.

SHORE WATER: A broad term for classifying water originating from a source ashore.

SHUTOFF VALVE: A valve which operates fully open or fully closed.

SIMPLEX PUMP: A pump that has only one liquid cylinder.

SLEEVE: A casing fitted over a line or shaft for protection against wear or corrosion.

SOLENOID: An electromagnetic coil that contains a movable plunger.

SOLID COUPLING: A device that joins two shafts rigidly.

SOUNDING PIPE or SOUNDING TUBE: A vertical pipe in an oil or water tank, used to guide a sounding device during measurement of the depth of liquid in the tank.

SPECIFIC GRAVITY: The ratio of the weight of a given volume of any substance to the weight of an equal volume of distilled water. Since the distilled water weighs approximately 62.4 pounds per cubic foot, any substance which weighs less than this has a specific gravity of less than one and will float on water. Any substance of greater weight per cubic foot has a specific gravity of more than one and will sink. Specific gravity of gases is based in a like manner on the weight of air.

SPECIFIC HEAT: The amount of heat required to raise the temperature of 1 pound of a substance 1°F. All substances are compared to water which has a specific heat of 1 Btu/lb/°F.

SPEED DROOP: A progressive drop in speed as load is picked up by the prime mover from no load to full load without manually changing the speed setting.

SPEED-LIMITING GOVERNOR: A device for limiting the speed of a prime mover.

SPEED-REGULATING GOVERNOR: A device that maintains a constant speed on an engine that is operating under varying load conditions.

SPLIT PLANT: A method of operating propulsion plants so that they are divided into two or more separate and complete units.

SPRING BEARINGS: Bearings positioned at varying intervals along a propulsion shaft to help keep it in alignment and to support its weight.

STABILITY: The ability of a governor to correct a speed disturbance with a minimum of corrective motions.

STACK: Shipboard chimney.

STANDBY EQUIPMENT: Two auxiliaries that perform one function. When one auxiliary is running, the standby is so connected that it may be started if the first fails.

STATOR: The stationary element of a motor or generator.

STEAM: Vapor of water; invisible, odorless, tasteless, and usually under greater than atmospheric pressure.

STEERING ENGINE: The machinery that turns the rudder.

STEERING GEAR: A term applied to the steering wheels, leads, steering engine, and fittings by which the rudder is turned.

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STEP-TOOTHED LABYRINTH: Labyrinth type packing having each alternate tooth ring installed on the shaft and running in close proximity to the fixed packing ring.

STERN TUBE: (1) The bearing supporting the propeller shaft where it emerges from the ship. (2) A watertight enclosure for the propeller shaft.

STERN TUBE FLUSHING WATER: Water circulated through the stern tube from inboard to prevent accumulation of debris in the stern tube while the ship is at rest or backing down.

STUFFING BOX: A device to prevent leakage between a moving and a fixed part.

SUMP: A container, compartment, or reservoir used as a drain or receptacle for engine oil.

SUPERCHARGE: To supply a charge of air at a pressure higher than that of the surrounding atmosphere.

SUPERCHARGER: A device for increasing the volume of the air charge of an internal-combustion engine.

SUPERHEAT: Amount of heat applied to vapor to raise its temperature above the saturation temperature, while maintaining constant pressure.

SUPPLY AIR: Compressed air required for the proper operation of pneumatic control components.

SURGING: A rhythmic variation of speed of an engine which can be eliminated by blocking the fuel supply manually or with load limit and which will not reappear when returned to governor control unless the speed adjustment is changed or the load changes.

SWING CHECK VALVE: A valve that has a guide-mounted disk swung from the top by a horizontal pin. A liquid exerting pressure against the disk will cause it to open, allowing a flow. Pressure exerted in the opposite direction will close the valve, ensuring only one direction of flow.

SWITCHBOARD: A panel or group of panels with automatic protective devices, used to distribute the electrical power throughout the ship.

SYNCHRONIZE: To make two or more events or operations occur at the proper time with respect to each other. To adjust two engines to run at the same speed.

SYNTHRON SEAL: A rubber strip seal installed on the shaft to prevent seawater from leaking into the ship along the shaft.

TACHOMETER: An instrument for indicating revolutions per minute.

TAIL SHAFT: The aft section of the shaft which receives the propeller.

TAKE LEADS: A method of determining bearing and other clearances. Mostly replaced by other methods such as platigage and bearing shell thickness measurements.

TDC (top dead center): The position of a reciprocating piston at its uppermost point of travel.

TEFLON: A plastic with excellent self-lubricating bearing properties.

TELEGRAPH: An apparatus, either electrical or mechanical, for transmitting orders, as from a ship's bridge to the engineroom, steering gear room, or elsewhere about the ship.

TELEMOTOR: A device for operating the steering engine from the pilothouse by means of either fluid pressure or electricity.

TEMPER: To harden steel by heating and sudden cooling by immersion in oil, water, or other coolant.

TENSILE STRENGTH: The measure of a material's ability to withstand a tensile, or pulling, stress without rupture, usually measured in pounds or tons per square inch of cross section.

THERMAL ENERGY: Energy contained in, or derived from, heat.

THERMAL EXPANSION: The increase in volume of a substance due to temperature change.

THERMOCOUPLE: (1) A bimetallic device capable of producing an electromotive force roughly proportional to temperature differences on its hot and cold junction ends and used in the measurement of elevated temperatures. (2) A junction of two dissimilar metals that produces a voltage when heated.

THREAD: The spiral part of a screw.

THROAT: Opening in the cylinder block through which the crankshaft end is extended.

THROTTLEMAN: Person in the engineroom who operates the throttles to control the main engines.

THROTTLE VALVE: A type of valve especially designed to control rate of flow.

THROTTLING: Operating a valve partially open to produce a pressure drop with flow.

THRUST BEARINGS: Bearings that limit the axial (longitudinal) movement of the shaft.

TILLER: An arm attached to the rudder head for operating the rudder.

TOLERANCE: The amount that a manufactured part may vary from its specified size.

TOOL POST: A rigid support for the cutting tool.

TOP OFF: To fill up, as a ship tops off, with fuel oil before leaving port.

TORQUE: A force or combination of forces that produces or tends to produce a twisting or rotary motion.

TOUGHNESS: The property of a material which enables it to withstand shock as well as to be deformed without breaking.

TRANSDUCER: A device that converts signals received in one medium into outputs in some other medium; for example, electrical inputs to fluidic outputs.

TRANSFER VALVE: Manually operated direction valve used to switch automatic control systems from automatic to manual operation and vice versa.

TRANSFORMER: A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another. Also, an electrical device used to step up or step down an a.c. voltage.

TRANSMISSION: A device that transmits power from the engine (driving unit) to the load (driven unit).

TRICK WHEEL: A steering wheel in the steering engineroom or emergency steering station of a ship, used in case of emergency.

TUBING: That type of fluid line the dimensions of which are designated by actual measured outside diameter (OD) and by actual measured wall thickness.

TURBINE: (1) A rotary motor actuated by the reaction, impulse, or both, of a flow of pressurized fluid. A turbine usually consists of a series of curved vanes on a centrally rotating shaft. (2) A multibladed rotor, driven by steam, hot gas, or water.

TURBULENCE: Air in the combustion space in motion.

UNBURNABLE OIL: That quantity of oil below the stripping suction in storage tanks and below the service suction in service tanks.

UNIT INJECTOR: A diesel engine injector that combines a pump and a fuel-spray nozzle in a single unit.

UNSTABLE: That action of an automatic control system and controller process that is characterized by a continuous cycling of one or more system variables to a degree greater than a specified maximum.

VACUUM: Pressure less than atmospheric pressure.

VALVE: A mechanism that can be opened or closed to control or stop the flow of a liquid, gas, or vapor from one to another place.

VALVE LASH: Clearance between the top of the valve stem and the valve-lifting mechanism.

VALVE SEAT: The surface, normally curved, against which the valve disk's operating face comes to rest to provide a seal against leakage of liquid, gas or vapor.

VALVE SEAT INSERT: Metal ring inserted into valve seat, made of special metal that can withstand operating temperature satisfactorily.

VALVE SPRING: The compression-type spring that closes the valve when the valve-operating cam assumes a closed-valve position.

VAPOR: The gaseous state of a substance that is usually a liquid or solid at atmospheric temperature and pressure.

VARIABLE DISPLACEMENT: The type of pump or motor in which the volume of fluid delivered per cycle can be varied.

VELOCITY: The rate of motion in a particular direction. The velocity of fluid flow is usually measured in feet per second.

VENT: A valve in a system used primarily to permit air to escape.

VENTILATION SYSTEM: A system that removes heat and stale air and provides fresh air by means of mechanical or natural distribution ductwork. The system may also include filters and heaters.

VENTURI: A tube that has a narrowing throat or constriction to increase the velocity of fluid flowing through it. The flow through the venturi causes a pressure drop in the smallest section.

VIEW: A drawing of a side or plane of an object as seen from one point.

VISCOSIMETER: A device that determines the viscosity of a given sample of oil.

VISCOSITY: The internal resistance of a fluid which tends to prevent it from flowing.

VITAL CIRCUITS: Electrical circuits that provide power or lighting to equipment and spaces necessary for propulsion, ship control, and communications.

VOID: An empty tank.

VOLATILE: The term that describes a liquid which vaporizes quickly.

VOLT: The unit of electrical potential.

VOLTAGE TESTER: A portable instrument that detects electricity.

VOLTMETER: An instrument designed to measure a difference in electrical potential, in volts.

VOLUME OF FLOW: The quantity of fluid that passes a certain point in a unit of time. The volume of flow is usually expressed in gallons per minute for liquids and in cubic feet per minute for gases.

VOLUTE: A gradually widening spiral. A section or component of a centrifugal pump where velocity head becomes pressure head.

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WATER DRUM: A tank at the bottom of a boiler, sometimes called MUD DRUM, that equalizes distribution of water to the generating tubes and collects loose scale and other solids in boiler water.

WATER JACKET: Internal passages and cavities cast into the cylinder block of engines and air compressors through which water is circulated around and adjacent to friction (heat) areas.

WATER TUBE BOILER: Boiler in which the water flows through the tubes where it is heated by the gases of combustion.

WATT: The unit of electrical power.

WATTMETER: An instrument for measuring electrical power in watts.

WINCH: A hoisting or pulling machine fitted with a horizontal single or double drum. A small drum is generally fitted on one or both ends of the shaft supporting the hoisting drum. These small drums are called gypsies, or winch heads. The hoisting drums either are fitted with a friction brake or are directly keyed to the shaft. They are in the form of a spool and carry the working wire rope. The driving power is usually steam or electricity, but hand power is also used. A winch is used principally for handling, hoisting, and lowering cargo from a dock or lighter to the hold of a ship and vice versa.

WINDLASS: An apparatus in which horizontal or vertical drums or gypsies and wildcats are operated by means of a steam engine or motor for the purpose of handling heavy anchor chains, hawsers, etc.

WIPED BEARINGS: A bearing in which the babbitt has melted because of excess heat.

WORK: The transference of energy from one body or system to another.

WORK REQUEST: Request issued to naval shipyard, tender, or repair ship for repairs.

WORM, WORM SHAFT: A threaded shaft designed to engage the teeth of a wheel lying in the plane of the shaft axis. This type of gear is used for the transmission of heavy loads at low speeds.

WYE GATE: A fitting with two separately controlled hose fittings, designed to connect to an outlet.

YOKE: A frame or bar having its center portion bored and keyed or otherwise constructed for attachment to the rudder stock. Steering effort from the steering gear is applied to each end of the yoke for the purpose of turning the rudder.

ZERK FITTING: A small fitting to which a grease gun can be applied to force lubricating grease into bearings or moving parts of machinery.

ZERO SETTING: The output of a device when its input is minimum.

ZINC: A primary metal useful in a number of anticorrosion applications. A metal block or form placed in saltwater systems to counteract the effects of electrolysis.

APPENDIX II

U. S. CUSTOMARY AND METRIC SYSTEM UNITS OF MEASUREMENTS

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (tĕr'ȧ)	T
1 000 000 000 = 10^{9}	giga (jĭ'gȧ)	G
1 000 000 = 10^{6}	mega (mĕg'ȧ)	M*
1 000 = 10^{3}	kilo (kĭl'ō)	k*
100 = 10^{2}	hecto (hĕk'tȯ)	h
10 = 10	deka (dĕk'ȧ)	da
0.1 = 10^{-1}	deci (dĕs'ĭ)	d
0.01 = 10^{-2}	centi (sĕn'tĭ)	c*
0.001 = 10^{-3}	milli (mĭl'ĭ)	m*
0.000 001 = 10^{-6}	micro (mī'krȯ)	μ*
0.000 000 001 = 10^{-9}	nano (năn'ȯ)	n
0.000 000 000 001 = 10^{-12}	pico (pē'kȯ)	p
0.000 000 000 000 001 = 10^{-15}	femto (fĕm'tȯ)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (ăt'tȯ)	a

*Most commonly used

ENGLISH AND METRIC SYSTEM UNITS OF MEASUREMENT COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents		Conversions Accurate to Parts Per Million (units stated in abbreviated form) Number X Factor	
1 inch	= 25 millimeters	in X 25.4*	= mm
1 foot	= 0.3 meter	ft X 0.3048*	= m
1 yard	= 0.9 meter	yd X 0.9144*	= m
1 mile†	= 1.6 kilometers	mi X 1.60934	= km
1 square inch	= 6.5 square centimeters	in^2 X 6.4516*	= cm^2
1 square foot	= 0.09 square meter	ft^2 X 0.0929030	= m^2
1 square yard	= 0.8 square meter	yd^2 X 0.836127	= m^2
1 acre	= 0.4 hectare	acres X 0.404686	= ha
1 cubic inch	= 16 cubic centimeters	in^3 X 16.3871	= cm^3
1 cubic foot	= 0.03 cubic meter	ft^3 X 0.0283168	= m^3
1 cubic yard	= 0.8 cubic meter	yd^3 X 0.764555	= m^3
1 quart (1q.)	= 1 liter	qt (1q.) X 0.946353	= *l*
1 gallon	= 0.004 cubic meter	gal X 0.00378541	= m^3
1 ounce (avdp)	= 28 grams	oz (avdp) X 28.3495	= g
1 pound (avdp)	= 0.45 kilogram	lb (avdp) X 0.453592	= kg
1 horsepower	= 0.75 kilowatt	hp X 0.745700	= kW
1 pound per square inch	= 0.07 kilogram per square centimeter	psi X 0.0703224	= kg/cm^2
1 millimeter	= 0.04 inch	mm X 0.0393701	= in
1 meter	= 3.3 feet	m X 3.28084	= ft
1 meter	= 1.1 yards	m X 1.09361	= yd
1 kilometer	= 0.6 mile	km X 0.621371	= mi
1 square centimeter	= 0.16 square inch	cm^2 X 0.155000	= in^2
1 square meter	= 11 square feet	m^2 X 10.7639	= ft^2
1 square meter	= 1.2 square yards	m^2 X 1.19599	= yd^2
1 hectare	= 2.5 acres	ha X 2.47105	= acres
1 cubic centimeter	= 0.06 cubic inch	cm^3 X 0.0610237	= in^3
1 cubic meter	= 35 cubic feet	m^3 X 35.3147	= ft^3
1 cubic meter	= 1.3 cubic yards	m^3 X 1.30795	= yd^3
1 liter	= 1 quart (1q.)	*l* X 1.05669	= qt (1q.)
1 cubic meter	= 250 gallons	m^3 X 264.172	= gal
1 gram	= 0.035 ounces (avdp)	g X 0.0352740	= oz (avdp)
1 kilogram	= 2.2 pounds (avdp)	kg X 2.20462	= lb (avdp)
1 kilowatt	= 1.3 horsepower	kW X 1.34102	= hp
1 kilogram per square centimeter	= 14.2 pounds per square inch	kg/cm^2 X 14.223226	= psi

†nautical mile = 1.852 kilometers

* exact

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ENGINEMAN 3 & 2

NAVEDTRA 10541-C

Prepared by the Naval Education and Training Program Development
Center, Pensacola, Florida

Your NRCC contains a set of assignments and self-scoring answer sheets (packaged separately). The Rate Training Manual, ENGINEMAN 3&2 NAVEDTRA 10541-C , is your textbook for the NRCC. If an errata sheet comes with the NRCC, make all indicated changes or corrections. Do not change or correct the textbook or assignments in any other way.

HOW TO COMPLETE THIS COURSE SUCCESSFULLY

Study the textbook pages given at the beginning of each assignment before trying to answer the items. Pay attention to tables and illustrations as they contain a lot of information. Making your own drawings can help you understand the subject matter. Also, read the learning objectives that precede the sets of items. The learning objectives and items are based on the subject matter or study material in the textbook. The objectives tell you what you should be able to do by studying assigned textual material and answering the items.

At this point you should be ready to answer the items in the assignment. Read each item carefully. Select the BEST ANSWER for each item, consulting your textbook when necessary. Be sure to select the BEST ANSWER from the subject matter in the textbook. You may discuss difficult points in the course with others. However, the answer you select must be your own. Use only the self-scoring answer sheet designated for your assignment. Follow the scoring directions given on the answer sheet itself and elsewhere in this course.

Your NRCC will be administered by your command or, in the case of small commands, by the Naval Education and Training Program Development Center. No matter who administers your course you can complete it successfully by earning grades that average 3.2 or higher. If you are on active duty, the average of your grades in all assignments must be at least 3.2. If you are NOT on active duty, the average of your grades in all assignments of each creditable unit must be at least 3.2. The unit breakdown of the course, if any, is shown later under Naval Reserve Retirement Credit.

WHEN YOUR COURSE IS ADMINISTERED BY LOCAL COMMAND

As soon as you have finished an assignment, submit the completed self-scoring answer sheet to the officer designated to administer it. He will check the accuracy of your score and discuss with you the items that you do not understand. You may wish to record your score on the assignment itself since the self-scoring answer sheet is not returned.

If you are completing this NRCC to become eligible to take the fleetwide advancement examination, follow a schedule that will enable you to complete all assignments in time. Your schedule should call for the completion of at least one assignment per month.

Although you complete the course successfully, the Naval Education and Training Program Development Center will not issue you a letter of satisfactory completion. Your command will make a note in your service record, giving you credit for your work.

WHEN YOUR COURSE IS ADMINISTERED BY THE NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER

After finishing an assignment, go on to the next. Retain each completed self-scoring answer sheet until you finish all the assignments in a unit (or in the course if it is not divided into units). Using the envelopes provided,

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mail your self-scored answer sheets to the Naval Education and Training Program Development Center where the scores will be verified and recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. You may wish to record your scores on the assignments since the self-scoring answer sheets are not returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course). To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

You may keep the textbook and assignments for this course. Return them only in the event you disenroll from the course or otherwise fail to complete the course. Directions for returning the textbook and assignments are given on the book-return form in the back of this NRCC.

PREPARING FOR YOUR ADVANCEMENT EXAMINATION

Your examination for advancement is based on the Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards (NAVPERS 18068). The sources of questions in this examination are given in the Bibliography for Advancement Study (NAVEDTRA 10052). Since your NRCC and textbook are among the sources listed in this bibliography, be sure to study both in preparing to take your advancement examination. The qualifications for your rating may have changed since your course and textbook were printed, so refer to the latest editions of NAVPERS 18068 and NAVEDTRA 10052.

NAVAL RESERVE RETIREMENT CREDIT

This course is evaluated at 30 Naval Reserve retirement points. These points are creditable to personnel eligible to receive them under current directives governing retirement of Naval Reserve personnel. Points will be credited in units as follows:

UNIT 1: 12 points upon satisfactory completion of Assignments 1 through 6.

UNIT 2: 12 points upon satisfactory completion of Assignments 7 through 12.

UNIT 3: 6 points upon satisfactory completion of Assignments 13 through 15.

Naval Reserve retirement credit will not be given if the student has previously received credit for any Engineman 3 & 2 ECC or NRCC.

COURSE OBJECTIVE

Upon completion of the course assignments you will have demonstrated improved professional competence by selecting correct answers to questions about the following subjects: the construction, design, operation, and maintenance of diesel engines, reduction gears and related auxiliary equipment and supporting systems; the design of gas turbine engines; the design, construction, application, and maintenance of mechanical components such as pumps, valves, and control devices; the design, operation, and maintenance of marine auxiliary equipment, specifically compressed air systems, evaporators, refrigeration and air conditioning systems, deck machinery, steering gear, and laundry and galley equipment; and the construction and use of the common engine lathe.

While working on this nonresident career course, you may refer freely to the text. You may seek advice and instruction from others on problems arising in the course, but the solutions submitted must be the result of your own work and decisions. You are prohibited from referring to or copying the solutions of others, or giving completed solutions to anyone else taking the same course.

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Naval nonresident career courses may include a variety of items -- multiple-choice, true-false, matching, etc. The items are not grouped by type; regardless of type, they are presented in the same general sequence as the textbook material upon which they are based. This presentation is designed to preserve continuity of thought, permitting step-by-step development of ideas. Some courses use many types of items, others only a few. The student can readily identify the type of each item (and the action required of him) through inspection of the samples given below.

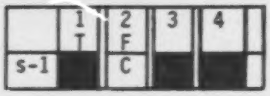
MULTIPLE-CHOICE ITEMS

Each item contains several alternatives, one of which provides the best answer to the item. Select the best alternative and erase the appropriate box on the answer sheet.

SAMPLE

s-1. The first person to be appointed Secretary of Defense under the National Security Act of 1947 was
1. George Marshall
2. James Forrestal
3. Chester Nimitz
4. William Halsey

The erasure of a correct answer is indicated in this way on the answer sheet:



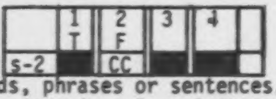
TRUE-FALSE ITEMS

Determine if the statement is true or false. If any part of the statement is false the statement is to be considered false. Erase the appropriate box on the answer sheet as indicated below.

SAMPLE

s-2. Any naval officer is authorized to correspond officially with a bureau of the Navy Department without his commanding officer's endorsement.

The erasure of a correct answer is also indicated in this way on the answer sheet:



MATCHING ITEMS

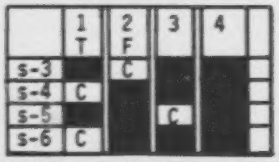
Each set of items consists of two columns, each listing words, phrases or sentences. The task is to select the item in column B which is the best match for the item in column A that is being considered. Items in column B may be used once, more than once, or not at all. Specific instructions are given with each set of items. Select the numbers identifying the answers and erase the appropriate boxes on the answer sheet.

SAMPLE

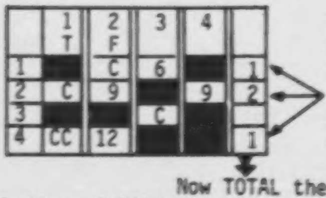
In items s-3 through s-6, match the name of the shipboard officer in column A by selecting from column B the name of the department in which the officer functions.

A. Officers	B. Departments
s-3. Damage Control Assistant	1. Operations Department
s-4. CIC Officer	2. Engineering Department
s-5. Assistant for Disbursing	3. Supply Department
s-6. Communications Officer	

The erasure of a correct answer is indicated in this way on the answer sheet:



How To Score Your Immediate Knowledge of Results (IKOR) Answer Sheets



Total the number of incorrect erasures (those that show page numbers) for each item and place in the blank space at the end of each item.

Sample only

Number of boxes erased incorrectly	0-2	3-7	8-
Your score	4.0	[✓ 3.9]	3.8

Now TOTAL the column(s) of incorrect erasures and find your score in the Table at the bottom of EACH answer sheet.

NOTICE: If, on erasing, a page number appears, review text (starting on that page) and erase again until "C", "CC", or "CCC" appears. For courses administered by the Center, the maximum number of points (or incorrect erasures) will be deducted from each item which does NOT have a "C", "CC", or "CCC" uncovered (i.e., 3 pts. for four choice items, 2 pts. for three choice items, and 1 pt. for T/F items).

Assignment 1

Advancement and Reciprocating Internal-Combustion Engines

Textbook Assignment: Pages 1 through 23

In this course you will demonstrate that learning has taken place by correctly answering training items. The mere physical act of indicating a choice on an answer sheet is not in itself important; it is the mental achievement, in whatever form it may take, prior to the physical act that is important and toward which course learning objectives are directed. The selection of the correct choice for a course training item indicates that you have fulfilled, at least in part, the stated objective(s).

The accomplishment of certain objectives, for example, a physical act such as drafting a memo, cannot readily be determined by means of objective type course items; however, you can demonstrate by means of answers to training items that you have acquired the requisite knowledge to perform the physical act. The accomplishment of certain other learning objectives, for example, the mental acts of comparing, recognizing, evaluating, choosing, selecting, etc., may be readily demonstrated in a course by indicating the correct answers to training items.

The comprehensive objective for this course has already been given. It states the purpose of the course in terms of what you will be able to do as you complete the course.

The detailed objectives in each assignment state what you should accomplish as you progress through the course. They may appear singly or in clusters of closely related objectives, as appropriate; they are followed by items which will enable you to indicate your accomplishment.

All objectives in this course are learning objectives and items are teaching items. They point out important things, they assist in learning, and they should enable you to do a better job for the Navy.

This self-study course is only one part of the total Navy training program; by its very nature it can take you only part of the way to a training goal. Practical experience, schools, selected reading, and the desire to accomplish are also necessary to round out a fully meaningful training program.

Learning Objective: Identify the Engineman rating, listing some of the duties and responsibilities of the personnel who hold this rating. Textbook page 1.

1-1. Which of the following is a description of the Engineman rate?

1. A general rating in the engineering group
2. A special rating held by those who operate only one kind of engine
3. A service rating within the Machinist's Mate rate
4. A service rating within any engineering and hull group rate

1-2. A general rating identifies a/an

1. individual's job qualifications
2. specialty used in wartime
3. broad occupational field of related duties and functions
4. individual's performance in completing his Personnel Advancement Requirements (PAR)

1-3. An Engineman in M division will most probably be assigned to maintain

1. steering gear
2. refrigeration equipment
3. cranes and winches
4. propulsion machinery

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1-4. As you move up the promotion ladder to EN3 or EN2, which of the following describes your technical leadership responsibilities?

1. They will be more general in nature
2. They will be more directly related to your work
3. They will include more military responsibilities than for personnel who hold other ratings
4. They will require only that you tell others what to do

1-5. An Engineman demonstrates technical leadership best by

1. performing work with integrity and increasing knowledge
2. developing military leadership
3. taking pride in military appearance
4. demonstrating the manual of arms

1-6. How can you demonstrate integrity of work?

1. By standing watches
2. By repairing leaky valves
3. By cleaning your equipment
4. By performing each of the above as well as you can

Learning Objective: Discuss the purpose of Navy Enlisted Classification Codes (NEC'S). Textbook page 2.

1-7. Which of the following is a purpose of the Navy Enlisted Classification Codes (NEC's)?

1. To recruit Navy men and women
2. To identify skills and training required for specific types of operations or equipment
3. To determine who will advance
4. To classify information about ships

● NAVPERS 18068, The Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards lists the NEC's that you are eligible to try for.

1-8. Where can you find a copy of NAVPERS 18068?

1. In the Log Room
2. In the Personnel Office
3. In the Supply Office
4. In the Operations Office

Learning Objective: Identify the essentials of the Navy Enlisted Advancement System. Textbook pages 2 through 9.

1-9. Which of the following is/are required for advancement in rating to EN3 or EN2?

1. Recommendation of your commanding officer
2. Passing a written examination on occupational standards applicable to your rate
3. Length of time in paygrade
4. All of the above

1-10. Which of the following is NOT a requirement for advancement in rating to EN3 or EN2?

1. Demonstrate ability to do everything listed for EN3 or EN2 in the Personnel Advancement Requirement (PAR) Program (NAVPERS 1414/4)
2. Pass a written E-4 or E-5 Military/Leadership examination
3. Complete the mandatory Rate Training Manual, Engineman 3&2
4. Demonstrate knowledge of subject matter in related ratings at the same paygrade

1-11. What factor(s) determine(s) your final multiple score?

1. Score on advancement examination
2. Length of time in rate
3. Performance marks
4. Each of the above

1-12. To find the required and recommended training courses to study for advancement in rating, what publication should you consult?

1. Navy Enlisted Manpower and Personnel Classifications and Occupational Standards, NAVPERS 18068 (current series)
2. Bibliography for Advancement Study, NAVEDTRA 10052 (current series)
3. Guide for Enlisted Classification
4. Shipboard Training Manual

1-13. When studying for advancement, remember that you will be tested on the standards that apply to

1. the rate level to which you seek advancement
2. your present and lower rate levels
3. the rate level you seek and higher levels
4. the rate level to which you seek advancement and lower levels

1-14. Who schedules the Military/Leadership Examinations?

1. Chief of Naval Personnel
2. Commanding Officer
3. Division Officer
4. Education Services Officer

1-15. What do Occupational Standards identify?

1. Military requirements
2. Leadership requirements
3. Work requirements
4. Each of the above

1-16. Where are (a) Naval Standards and (b) Occupational Standards found in NAVPERS 18068?

1. (a) Section I (b) Section II
2. (a) Section II (b) Section I
3. (a) Section I (b) Section I
4. (a) Section II (b) Section II

- In answering items 1-17 and 1-18, refer to figures 1-3 and 1-4 of the text.

1-17. After studying piping and valves what topic should you study next?

1. Propulsion
2. Casualty control
3. Auxiliary machinery
4. Distilling

1-18. What information is found in block (2) of your Profile Information Form?

1. Examination status
2. Your final multiple
3. Minimum multiple required
4. Standing

1-19. Which of the following replaces the Record of Practical Factors?

1. Personnel Qualification Standards
2. Engineering Operations Sequencing System
3. Personnel Advancement Requirement (PAR) Program
4. Occupational Standards

1-20. What paygrades, if any, are exempted from the Personnel Advancement Requirement (PAR) Program?

1. E-3 apprenticeships, E-8, and E-9
2. E-8 and E-9 only
3. E-3 apprenticeships only
4. None

1-21. What information is found in Section II of the PAR?

1. Formal School and Training Requirements
2. Administration Requirements
3. Occupational Requirements
4. Military Ability Requirements

Learning Objective: Describe the functions of the Engineering Operational Sequencing System (EOSS). Textbook page 9.

1-22. Which of the following describes EOSS?

1. A group of general procedures that covers all ships of the same class
2. Details the sequential operational functions for the complete cycle of plant evolutions
3. Includes PMS and PQS
4. Improves everything except watchstanding

1-23. EOSS will standardize watchstanding between ships.

1-24. The primary goal of EOSS is to improve operational readiness by improvements in operation and casualty control procedures. What is the secondary feature of EOSS?

1. To provide a PAR checkoff procedure
2. To provide aid in training new men
3. To improve 3-M procedures
4. To standardize proficiency

Learning Objective: Discuss the purposes of Personnel Qualification Standards. Textbook pages 9 and 10.

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1-25. Which of the following functions is NOT served by the Personnel Qualifications Standards?

1. Describing the knowledge and skills a trainee must have to perform duties correctly
2. Providing a petty officer to teach the learner in each step of work
3. Individualizing learning
4. Placing responsibility for learning on the learner

1-26. Personnel Qualifications Standards support the advancement in rating requirements which are given in the

1. Basic Military Requirements, NAVTRA 10054-D
2. Bibliography for Advancement Study, NAVEDTRA 10052 series
3. Navy Enlisted Manpower and Personnel Classifications and Occupational Standards NAVPERS 18068 series
4. Personnel Advancement Requirement (PAR) Program, NAVPERS 1414/4

1-27. Which subject section is NOT contained in the Personnel Qualification Standards?

1. 100 series - Theory
2. 300 series - Watchstanding
3. Feedback forms
4. Maintenance

Learning Objective: Identify the purpose, benefits, and limitations of the Planned Maintenance System. Textbook page 10.

1-28. Which of the following is NOT a purpose of the Planned Maintenance System (PMS)?

1. To administer examinations on maintenance theory
2. To provide for detection and prevention of impending casualties
3. To describe the methods and tools to be used
4. To estimate and evaluate material readiness

1-29. Which of the following actions is NOT required for the Planned Maintenance System to be successful?

1. Professional guidance from several available sources
2. Obtaining a degree in management
3. Direction at each echelon of the organization
4. Training in the maintenance steps and in the system

Learning Objective: List sources of information for Enginemen who wish to advance in their careers. Textbook pages 11 through 14.

1-30. When studying for advancement, which of the following publications will be a hinderance?

1. NAVSEA Journal
2. Blueprint Reading and Sketching
3. Naval Ships' Technical Manual
4. Obsolete rate training manuals

1-31. If extensive changes occur in the qualifications for a rating between the annual publications of NAVEDTRA 10052, where can you find a list of study material?

1. NAVAL SEA SYSTEMS Notices
2. BUPERS Notice
3. NAVEDTRA 10052 supplements
4. Naval Ships' Technical Manual

1-32. Which of the courses listed in NAVEDTRA 10052 for your rating must you complete to be eligible to take the advancement in rating examinations?

1. All courses listed for the Engineering and Hull group
2. All courses listed for the next higher rate
3. Courses marked with an asterisk at the next higher rate
4. Unmarked courses listed for the next higher rate

1-33. Assume that you are an EN3 preparing to take the servicewide advancement in rate examination for EN2. Which courses and references listed in NAVEDTRA 10052 series will you be examined on?

1. All courses and references listed for E-4 and E-5 for the EN rating
2. All courses listed for E-5 Engineering ratings
3. Courses marked with an asterisk for E-5 and E-6 in the EN rating
4. Courses marked with an asterisk for E-5 Engineering/Hull ratings and all references for E-5 Engineering/Hull rating

In items 1-34 through 1-36, select the publication from column B that is a source of the information in column A.

	A. Information	B. NAVEDTRA Publications
1-34.	Knowledge and skills applicable to each paygrade within the Engineman rating	1. Navy Enlisted Manpower and Personnel Classifications and Occupational Standards
1-35.	Latest edition of a given Rate Training Manual	2. Bibliography for Advancement Study, NAVEDTRA 10052 series
1-36.	References used for source material for advancement examinations	3. List of Training Manuals and Correspondence Course, NAVEDTRA 10061 series
		4. The Metric System, NAVEDTRA 475-01-00-75-1

1-37. Each rate training manual contains information relating directly to the occupational qualifications of several ratings.

1-38. What is the best source of definitions to the technical terms used in your textbook?

1. Your leading chief
2. Glossary at the end of the text
3. Webster's New Collegiate Dictionary
4. Each chapter of your text

1-39. Which of the following hints for studying should help you get the most from your Navy training course?

1. Devote your time exclusively to important military topics
2. Try not to cover a complete unit in any one study period
3. Omit easy material; study only the most difficult and the unfamiliar
4. Make notes as you study, putting the main ideas in your own words; then review your notes

1-40. As you study a Navy training course, what study practice should you follow?

1. Set up a fixed number of pages to study in each and every study period
2. Tie in new information with things you know already
3. Memorize as much as you can from a chapter and repeat it to a shipmate
4. Skip over the illustrations and save them until the end of your course

1-41. Which of the following is a monthly publication that contains useful articles about shipboard engineering and information concerning new developments?

1. Change to NAVSHIPS' Technical Manual
2. NAVSEA Journal
3. Supplement to applicable Navy Training Course
4. Bibliography for Advancement Study

1-42. Aboard ship, blueprints are filed according to

1. month and year of issue
2. SHIPALT number
3. numerical sequence in the ship's drawing index (SDI)
4. revision number or letter

Learning Objective: Correctly use technical language to describe the principles of operation of gasoline and diesel engines. Textbook pages 16 through 23.

1-43. Diesel engines are classified as reciprocating internal-combustion engines because they

1. use energy from fuel burned outside their cylinders
2. burn fuel in a combustion chamber that moves back and forth
3. burn fuel in a chamber where its energy moves a piston back and forth
4. use a continuous combustion process to impart rotary motion to the pistons

1-44. In a diesel engine, internal combustion causes the piston to move by

1. the admission of fuel and air into the combustion space
2. pressure of gases produced and heated by the burning of fuel and air in the cylinder
3. specially designed parts connected to a shaft
4. the concept of reciprocity

1-45. The thermal energy produced by internal combustion in an engine is transformed into

1. combustion energy
2. internal energy
3. external energy
4. mechanical energy

1-46. In describing engine operation, what does the term "cycle" mean?

1. The sequence of events that produces a power pulse
2. One rotation of the engine crankshaft
3. One stroke of a piston
4. Any of the above

1-47. What determines the number of events occurring in a cycle of operation?

1. Crankshaft revolution
2. Type of engine (diesel or gasoline)
3. Distance a piston travels during a stroke
4. Number of pistons

1-48. In describing engine operation, what does the term "event" mean?

1. The production of high-pressure gases
2. The removal of expended combustion gases
3. The admission of air to the cylinder
4. All of the above

1-49. The diesel engine cycle includes six events; the gasoline cycle includes five. Which event occurs only in the diesel engine cycle?

1. Compression event
2. Combustion event
3. Fuel injection event
4. Power event

1-50. When is fuel injected into a cylinder of diesel engines?

1. Before air in the cylinder is compressed
2. After air in the cylinder is compressed
3. After combustion gases in the cylinder have expanded
4. As air is taken into the cylinder

1-51. One cycle of engine operation includes

1. one combustion cycle
2. one mechanical cycle
3. one mechanical and one combustion cycle
4. either half a mechanical cycle or an entire mechanical cycle depending on engine type

1-52. Which of the following is referred to as the combustion cycle?

1. The mechanics of engine operation
2. The heat process which produces the forces that move engine parts
3. Number of piston strokes involved
4. The mechanical equivalent of heat

1-53. What term describes the series of heat and pressure processes that compose a cycle of engine operation?

1. Operating cycle
2. Mechanical cycle
3. Either mechanical or operating cycle
4. Combustion cycle

1-54. A piston in a 4-stroke cycle engine makes four strokes during each

1. crankshaft revolution
2. mechanical cycle of operation
3. period of two combustion cycles
4. cycle of two events

1-55. The functional difference between a 2-stroke and a 4-stroke cycle engine is in the number of

1. piston strokes each one needs to complete a combustion cycle
2. piston strokes each one needs to complete a complete revolution
3. strokes in each combustion event
4. combustion event occurring in each stroke

1-56. The two strokes of a 2-stroke cycle engine are

1. power and intake
2. intake and exhaust
3. exhaust and compression
4. compression and power

1-57. At the instant a piston is at bottom dead center, the motion of the crankshaft is (a)___ and the motion of the piston is (b)___.

1. (a) continuous (b) downward
2. (a) stopped (b) stopped
3. (a) continuous (b) stopped
4. (a) downward (b) downward

Match events in a 4-stroke cycle engine in column B with the occurrences and motions of engine parts in column A.

	A. Occurrence and Motion	B. Event
1-58.	Piston descending, air entering cylinder	1. Compression
1-59.	Piston ascending, air charge retained in cylinder	2. Exhaust
		3. Intake
1-60.	Piston descending, fuel burning	4. Power
1-61.	Piston descending, waste gases leaving cylinder	

1-62. Which event does NOT occur during the instant the piston just reaches top dead center?

1. Intake
2. Ignition
3. Power
4. Exhaust

1-63. What two events occur simultaneously in a 2-stroke cycle engine?

1. Exhaust and scavenging
2. Scavenging and compression
3. Ignition and expansion
4. Exhaust and compression

1-64. For a given size engine, the 2-stroke cycle engine will deliver more power than a 4-stroke cycle engine because

1. it has a longer power stroke
2. more air gets into the cylinder each stroke
3. it develops twice as many power strokes at the same speed
4. higher combustion pressures are developed

The terms "otto" and "diesel" are from the names of the internal-combustion engine inventors. From the list below find the characteristic in column B that is peculiar to the design of each inventor in column A.

	A. Inventor	B. Characteristic
1-65.	Otto	1. Operates on a 2-stroke cycle
1-66.	Diesel	2. Achieves fuel ignition through high compression
		3. Operates on a 4-stroke cycle
		4. Achieves fuel ignition through an electrical spark

1-67. What is the relationship between the temperature developed in a combustion space and the compression ratio of the engine?

1. Higher compression ratios create higher temperatures
2. Higher temperatures create higher compression ratios
3. Lower temperatures create higher compression ratios
4. Higher compression ratios create lower temperatures

1-68. In a diesel engine after ignition of the fuel and before the piston reaches TDC, there is little change in

1. volume
2. pressure
3. temperature
4. energy

1-69. Why is the designed compression ratio of a gasoline engine lower than that of a diesel engine?

1. Compression must be low for effective spark ignition
2. Compression must be low for smooth operation
3. Compression must be low to prevent pre-ignition
4. Compression must be low to have effective pre-ignition

1-70. An indicator card, or pressure-volume diagram, shows graphically the

1. compression ratio of the engine
2. volume of the engine
3. relationships between pressure and volume during one stroke of the engine
4. relationships between pressure and volume during one cycle of the engine

Match the relationships of pressure and volume in a theoretical otto cycle engine (column B) with the events in column A.

A. Event	B. Relationship
1-71. Combustion	1. Pressure increasing, volume decreasing
1-72. Exhaust	2. Pressure decreasing, volume constant
	3. Pressure decreasing, volume increasing
	4. Pressure increasing, volume constant

Match the relationships of pressure and volume in a theoretical diesel cycle engine (column B) with the events in column A.

A. Event	B. Relationship
1-73. Compression	1. Pressure decreasing, volume increasing
1-74. Combustion	2. Pressure constant, volume decreasing
1-75. Exhaust	3. Pressure decreasing, volume constant
	4. Pressure increasing, volume increasing

Assignment 2

Reciprocating Internal-Combustion Engines (Continued); Principal Stationary Parts of an Engine; and Principal Moving and Related Parts

Textbook Assignment: Pages 24 through 60

Learning Objective: Correctly use technical language to describe the principles of operation of gasoline and diesel engines. Textbook pages 24 through 26.

2-1. During the compression stroke in a 4-stroke Otto cycle engine, assume that a piston moves seven-eighths of the total distance from BDC to TDC. What is the compression ratio?

1. 6 to 1
2. 7 to 1
3. 7.5 to 1
4. 8 to 1

2-2. In the Otto cycle, the fuel-air mixture is ignited at what point and by what means?

1. At TDC by heat generated by compression
2. Just before TDC by heat generated by compression
3. Just before TDC by spark ignition
4. At TDC by spark ignition

2-3. Which characteristic of the Otto cycle occurs in the actual diesel cycle but NOT in the theoretical diesel cycle?

1. No pressure increase during combustion
2. Rapid pressure increase during combustion
3. Rapid volume increase during combustion
4. No volume increase during combustion

2-4. The complete combustion event in a diesel engine occurs slightly before the piston reaches top dead center.

2-5. In a 2-stroke cycle engine the exhaust event requires a full stroke of the piston.

Learning Objective: Describe and compare the construction and characteristics of opposed piston engines and single-acting engines. Textbook pages 27 through 32.

2-6. An engine having a combustion chamber located between a cylinder head and the crown of a piston is of which of the following types?

1. Double acting
2. Opposed
3. Single acting
4. Horizontal opposed

2-7. An engine having a combustion chamber located between the crowns of two pistons is of which of the following types?

1. Double acting
2. Opposed piston
3. Single acting
4. Horizontal opposed

2-8. Which of the following is NOT found in single-acting engines?

1. Exhaust valves
2. Scavenging ports
3. Combustion chambers
4. Double crankshafts

Match the parts of an opposed piston engine in column A with the locations in the engine in column B.

A. Part	B. Location
2-9. Inlet (scavening) port	1. Bottom of cylinder
2-10. Exhaust ports	2. Between the crankshafts
2-11. Injector nozzle	3. Top of cylinder
2-12. Vertical drive	4. Middle of cylinder

2-13. In an opposed piston engine, the term "crank lead" means that

1. one crankshaft turns faster than the other
2. the two crankshafts turn in different directions
3. one piston in a cylinder reaches inner dead center before the other
4. one piston in a cylinder reaches inner dead center when the other reaches outer dead center

2-14. Crank lead is used to cause which of the following?

1. Longer combustion events
2. Exhaust events starting before scavenging events
3. Exhaust events lasting longer than scavenging events
4. Higher combustion temperatures

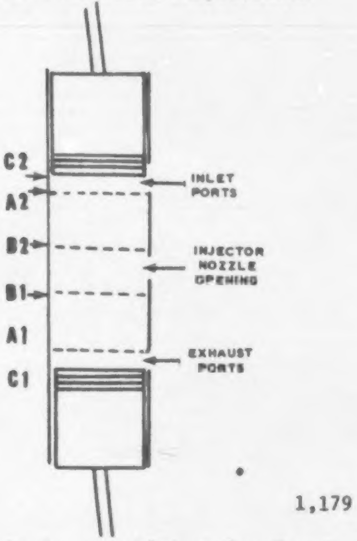

Figure 2A--Events in operating cycle of an opposed-piston engine.

- In answering 2-15 through 2-17, refer to figure 2A.

2-15. When the pistons in the figure are at points A1 and A2 and moving toward IDC, what event is taking place in the cylinder?

1. Compression
2. Expansion
3. Injection
4. Scavenging

2-16. Assume that the lower pistion is at point B1, a few degrees before IDC and moving toward IDC. The event now occurring in the cylinder is

1. expansion
2. injection
3. scavenging
4. supercharging

2-17. Which of the following events starts in the cylinder as the bottom piston approaches point C1?

1. Injection
2. Scavenging
3. Compression
4. Expansion

2-18. The difference in crank lead between the upper and lower cranks of the engine causes the lower shaft to

1. receive less power than the upper shaft
2. receive more power than the upper shaft
3. operate most of the engine's accessories
4. rotate faster than the upper shaft

Match the advantages in column A with the two principal types of engines in column B.

A. Advantages

2-19. Lighter weight

2-20. No valve problems

2-21. Do not require blowers

B. Type of Engine

1. Opposed-piston engines
2. Single-acting engines

Learning Objective: Point out the function of the stationary parts of the engine frame. Textbook pages 33 through 38.

2-22. What is the function of an engine's stationary parts?

1. To add power to the engine
2. To keep the engine firmly attached to its supporting base
3. To keep moving engine parts in their proper relative positions
4. To rotate the crankshaft

2-23. In a modern internal-combustion engine, the load-carrying part of the engine is referred to as the

1. bedplate or base
2. sump or oil pan
3. cylinder block
4. frame

2-24. In figure 3-1 of the textbook, what are the parts of the cylinder block labeled 6, 8, and 9?

1. Air boxes, air inlet ports, and camshaft boxes
2. Air inlet ports, water jackets, and handholes
3. Water jackets, air inlet ports, and cylinder liner boxes in the block
4. Lubricating oil passages, camshaft bores, and coolant passage

2-25. V-type cylinder blocks are usually constructed of forgings and steel plates welded together and always with the mounting pads for the main bearing seats as integral parts at the bottom of the block.

2-26. In some large engines of more modern design, what is the support for the main bearings?

1. Bedplate
2. Block
3. Base
4. Sump

2-27. In an engine, what is the purpose of end plates?

1. To provide accessibility to the cylinder liners
2. To add stability to the engine block
3. To add rigidity to the block and a surface for attaching other parts
4. To make a surface for the base

2-28. A safety cover differs from other access doors in that it is fitted with a

1. spring-loaded pressure plate
2. handwheel
3. nut-operated clamp
4. large gasket

2-29. The bearings that support the crankshaft are generally called

1. line shaft bearings
2. connecting rod bearings
3. main bearings
4. support bearings

Learning Objective: Identify cylinder assemblies with their functions, faults and repair procedures. Textbook pages 38 through 50.

2-30. The basic components of all cylinder assemblies along with related moving parts, provide a gas-tight and liquid-tight space. To accomplish this, a gasket is necessary between the head and block on all cylinder assemblies.

2-31. Cylinder liners that are an integral part of the block have which of the following disadvantages?

1. They conduct heat poorly
2. They are expensive
3. They cannot be replaced
4. They require special tools for removal

2-32. In an internal-combustion engine, which of the following materials is most commonly used for liner construction?

1. Close-grained steel
2. Close-grained cast iron
3. Close-grained Monel
4. Wear-resistant steel

2-33. Which of the following is the best description of a dry-type liner?

1. Thick wall, press fit, integral cooling passages
2. Thick wall, loose fit, water jacketed
3. Thin wall, pressed or loose fit without cooling passages
4. Thin wall, integral with block

2-34. When press-fit liners are replaced with loose-fit liners, what must be done to the cylinder bore?

1. It must be honed to a larger diameter
2. It must be replaced
3. It must be machined to a larger diameter
4. It must be heated to 150°F

2-35. In a wet-type liner that does not have integral cooling passages, the water jacket is formed by

1. an integral cooling passage in the block
2. a liner and a separate jacket which is part of the block
3. individual tubes which are inserted in the block
4. a liner and an integral cooling passage which is part of the block

2-36. Generally, the seal at the combustion end of a wet-type liner consists of a

1. gasket under a flange or machined fit
2. rubber or neoprene rings
3. labyrinth seal
4. nonhardening sealing compound

2-37. In a water-jacketed liner, water enters the lower section of the jacket and leaves through the top.

2-38. If a lip forms at the combustion end of a water-jacketed liner, which of the following parts is likely to break?

1. Connecting rod
2. Crankshaft
3. Piston ring
4. Cylinder head

2-39. In a cast-type jacket liner, how is the water jacket formed?

1. By the inner and outer walls of the liner
2. By the vertical passages
3. Both 1 and 2 above
4. Upper and lower O-rings

2-40. You are removing a cylinder liner from an engine. When fastening the special liner puller to the liner studs, why must you tighten the cap nuts by hand instead of by wrench?

1. The nuts cannot be reached with a wrench
2. The cylinder liner could be scratched with a wrench
3. Threads on both nuts and studs could be damaged by a wrench
4. There is some danger that a wrench will be left in the cylinder liner

2-41. Which of the following conditions could indicate a crack in the cylinder liner of an engine?

1. Water standing atop the cylinder's piston after the engine is secured
2. Abnormally high coolant temperature when the engine is operating
3. Large amounts of water in the lube oil
4. Any of the above

2-42. Which of the following will NOT result when a cylinder liner is improperly cooled?

1. Liner failure
2. Thermal stress
3. Uneven heating
4. Fluctuation in rpm

2-43. Which of the following is/are a symptom(s) of a scored cylinder?

1. Low compression pressure
2. Rapid wearing out of piston rings
3. Both 1 and 2 above
4. Cracked or broken piston rings

2-44. Broken piston rings will cause which of the following problems?

1. Scored cylinder liners
2. Connecting rod bearing failure
3. High lube oil temperature
4. High freshwater temperature

2-45. Which of the following conditions will produce out-of-round cylinder liners?

1. Operating the engine at a too low rpm
2. Defective main bearing
3. Piston side thrust
4. Improperly seated head

2-46. Corrosive vapors are most likely to condense on the cylinder liner walls of an engine while the engine is

1. operating at temperatures exceeding normal
2. operating with the lube oil pressure below normal
3. warming up after it is first started
4. operating in such a way that normal lube oil pressure is exceeded

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2-47. In a 2-stroke cycle engine with aluminum pistons, what is the maximum wear limit for the liner?

1. 0.0015 in. per inch diameter
2. 0.0025 in. per inch diameter
3. 0.003 in. per inch diameter
4. 0.005 in. per inch diameter

2-48. The spark plugs of a gasoline engine are always found in the cylinder head. In a diesel engine, what engine part almost invariably is located in the cylinder head or heads?

1. Intake valve
2. Air starting valve
3. Fuel injection valve
4. Rocker arm assembly

2-49. The ferrules or jumper lines in a diesel engine serve as

1. electrical timing devices for the parts in the head
2. loose joiners between the head and the block
3. connections between the coolant passages in the block and the head
4. connections to carry fuel oil from the block to the injectors in the head

2-50. You are inspecting a cylinder head for cracks. Which of the following procedures should you use?

1. After bringing the piston of each cylinder to top dead center, apply compressed air
2. Examine by sight or with magnetic powder
3. Perform the hydrostatic test which is used on water-jacketed cylinder liners
4. Any of the above methods

2-51. The gaskets which are used between the mating surfaces of the head and the block of an engine make this joint

1. acid resistant
2. leakproof
3. rigid
4. correctly shaped

2-52. What should yo do if you find a warped or distorted cylinder head?

1. Machine the head to correct tolerance
2. Replace the head as soon as possible
3. Overtorque the head until leakage stops
4. Reduce the load on the engine

2-53. Which of the following symptoms indicates fouling in the combustion spaces?

1. Excessive oil pumping
2. Smoky exhaust
3. Loss of power
4. All of the above

Learning Objective: Identify precautions and gaskets used in installing a cylinder head. Textbook pages 51 through 53.

2-54. What precaution should you take before installing nuts on cylinder head studs?

1. Apply strong soapsuds with a water lance
2. Clean threads with a wire brush and apply an approved solvent
3. Immerse stud nuts in acid, drain, and blow off remaining acid with air
4. Scrape stud nuts with a file and polish with a fine cloth

2-55. Compressibility is a common property of all gaskets. Which of the following materials is used to make gaskets?

1. Laminated steel sheets
2. Synthetic rubber
3. Copper
4. Any of the above

Learning Objective: Identify the functional parts of the engine mounting. Textbook pages 53 and 54.

2-56. The supporting and connecting pedestal between an engine and the ship's structure is referred to as the

1. engine base
2. subbase
3. chock
4. stud

2-57. Normally, which of the following mechanisms are NOT mounted to the ship's structure by shock absorbers and vibration isolators?

1. Engines that will receive shock loads from powerful explosions
2. Propulsion engines
3. Operating engines that develop high-frequency small-amplitude vibrations
4. Small generators mounted near the hull

Learning Objective: Distinguish between the function and characteristics of intake and exhaust valves. Textbook page 55.

● In an internal-combustion engine having both intake and exhaust valves, the intake valves are opened to admit air to the cylinder during the intake stroke, and exhaust valves are opened to discharge waste gases during the exhaust stroke.

2-58. Intake and exhaust valves used in internal-combustion engines are of what type?

1. Gas operated check
2. Spring activated
3. Cone-shaped seat
4. Poppet

2-59. What design feature(s) is/are found in an exhaust valve and NOT in an intake valve?

1. Hollow, sodium-filled stems
2. Beveled edges on the valve head
3. Alloy steel construction
4. All of the above

2-60. Why are low-alloy steels generally used for intake valves?

1. Because intake valves are exposed to the corrosive action of hot exhaust gases
2. Because intake valves are not exposed to the corrosive action of hot exhaust gases
3. Because low-alloy steels resist corrosion
4. Because intake valves are larger and need a hard alloy surface

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Learning Objective: Identify common causes of defective valve operation. Textbook pages 55 and 56.

2-61. Which valve casualty is/are probably caused by failure to close fully?

1. Burned valve
2. Valve float
3. Sticking valve
4. All of the above

2-62. Which valve casualty is probably caused by metal fatigue?

1. Burned valves
2. Valve float
3. Sticking valves
4. All of the above

2-63. Failure to properly prepare the counterbore area before placing a valve seat insert in it will cause what problem?

1. Uneven heat transfer between the seat and the counterbore
2. Scratching of the insert
3. Misalignment of the valve head in the seat
4. Loose fit of the insert in the counterbore

Learning Objective: Identify the principal valve maintenance procedures. Textbook pages 56 through 59.

2-64. When replacing a valve seat insert, which of these procedures should you NOT follow?

1. Plan the operation so the insert is placed rapidly
2. Use boiling water to heat the head
3. Drive the insert down with a heavy hammer
4. Shrink the insert with dry ice

2-65. Minor pits and flaws may be removed from a valve seat by

1. buffing
2. hand grinding
3. insert replacement
4. rubbing with prussian blue

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2-66. To avoid the condition shown in figure 4-5 of the text, hand grinding of valves should be done only

1. as a finishing operation
2. when the valve seat is pitted
3. when the cylinder head is off
4. before final dressing on a lathe

2-67. How are valves refaced?

1. On a lathe
2. Against the valve seat
3. Machine grinding
4. By any of the above means

2-68. What factors shorten the life of valve springs?

1. Compression and corrosion
2. Misalignment and compression
3. Corrosion and fatigue
4. Fatigue and compression

2-69. Which of the following does NOT warrant valve spring replacement?

1. Loss of 3% of length
2. Damage to protective coating
3. Hairline cracks
4. Rust pits

2-70. What will happen if shims are NOT properly placed between a valve stem and valve stem cap?

1. Damaged valve stem caps
2. Broken valve stems
3. Dropped valves
4. All of the above

Learning Objective: Identify the functions of the components of the valve actuating mechanisms. Textbook page 60.

2-71. Rocker arms transfer motion between what two components?

1. Crankshaft and camshaft
2. Camshaft and valves
3. Valves and pistons
4. Exhaust and intake valves

2-72. What design of valve actuating gears does NOT use push rods?

1. Cam shaft located in or near the cylinder head
2. Cam shaft located low on the cylinder block
3. Valve bridges used to open exhaust valves simultaneously
4. Two camshafts located in the block

2-73. Valve bridges are used to

1. operate two valves in sequence
2. operate two valves simultaneously
3. replace rocker arms
4. replace push rods

Assignment 3

Principal Moving and Related Parts (Continued)

Textbook Assignment: Pages 61 through 91

Learning Objective: Point out maintenance procedures for valve actuating gear. Textbook page 61.

3-1. What is the most important factor in keeping a properly adjusted valve actuating gear in good condition?

1. Minimum clearances
2. Control of corrosion
3. Proper materials
4. Adequate lubrication

3-2. The most common maintenance required for rocker arms is

1. reaming the bushings in the rocker arms
2. inspecting the rocker arm ends for wear
3. checking tappet clearances and locknut tightness
4. replacing tappet adjusting screws and locknuts

3-3. If the threads on a rocker arm adjusting screw become worn, what must you do?

1. Replace the rocker arm, screw, and nut
2. Replace the screw only
3. Replace the screw and locknut only
4. Dress the threads on the screw

3-4. To adjust the tappet to the intake valve of a 4-stroke cycle engine, the piston must be in what position?

1. On the intake stroke
2. On the compression stroke
3. Between the compression and power strokes
3. Between the intake and compression strokes

3-5. After setting a tappet clearance and locking the adjusting screw with the nut, what is your next step?

1. Recheck the clearance
2. Adjust the next tappet
3. Warm the engine up and reset the clearance
4. Check the manufacturer's manual to see if the clearance is correct

---

Learning Objective: Point out the functions of cam followers and lash adjusters. Textbook pages 61 through 63.

3-6. What is the function of cam followers?

1. To absorb friction from the cam shaft
2. To reduce tappet clearances
3. To replace the tappet setscrews
4. To transmit cam motion to the valve actuating mechanism

3-7. Hydraulic valve lifters perform the same function as

1. tappet setscrews
2. rocker arms
3. cam lobes
4. push rods

3-8. When a lash adjuster is adequately supplied with oil, what will most likely cause it to operate noisily?

1. Excessive clearance
2. Broken parts
3. Dirt, resin, or abrasive particles
4. Missing check ball or spring

Learning Objective: Point out the functions, faults, and corrective actions taken with faults of piston and rod assemblies. Textbook pages 63 through 77.

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3-9. Which of the following sources of stress does NOT apply to pistons?

1. Heat
2. Inertia
3. Pressure
4. Galvanic

3-10. What are the two most common materials for pistons?

1. Cast iron and magnesium
2. Magnesium and aluminum
3. Steel and aluminum
4. Aluminum and cast iron

3-11. Why is the crown of a piston usually smaller than the skirt?

1. It has more rings on it
2. It runs hotter
3. It absorbs no side thrust
4. It gets worn down faster

Match the purpose in column B with the design feature in column A.

A. Design Feature

3-12. Irregularly shaped piston

3-13. Concave piston crown

3-14. Recesses in rim of the crown

B. Purpose

1. To provide clearance for intake valve
2. To increase turbulence of the compressed air charge
3. To direct the flow of scavenging air and gases in a 2-stroke cycle engine
4. To transmit heat to the cylinder wall

3-15. The part(s) of a piston that absorb(s) side thrust is/are the

1. crown
2. bosses
3. lands
4. skirt

3-16. The piston rings are held in the

1. crown
2. bosses
3. lands
4. skirt

3-17. The piston pins are supported in the

1. crown
2. bosses
3. lands
4. skirt

3-18. How much of the combustion heat absorbed by the piston is removed through the rings to the cylinder wall?

1. 20%
2. 30%
3. 40%
4. 50%

3-19. Other than heat transmitted to the cylinder walls, what are the two factors that cool a piston?

1. Intake air and lube oil
2. Intake air and exhaust
3. Piston speed and crankcase air
4. Lube oil and cooling fins

3-20. Older designs of crosshead pistons were developed to handle the strong side thrusts of very long strokes. Modern crosshead pistons are designed to handle side thrusts and stresses due to

1. long strokes
2. high speeds
3. high compression
4. turbocharging

3-21. Which of the following is NOT a function of piston rings?

1. Sealing against combustion gases
2. Spreading oil on the cylinder wall
3. Keeping all oil out of combustion areas
4. Transferring heat to the cylinder wall

3-22. Which of the following characteristics does NOT apply to compression rings?

1. They commonly have a rectangular cross section
2. Their diameter, as manufactured, is a little more than the cylinder bore
3. Combustion gases act only on their top surfaces
4. They are usually made of cast iron

3-23. A properly working compression ring will be blackened on

1. one side
2. two sides
3. three sides
4. four sides

3-24. A piston ring which is composed of three separate pieces is a/an

1. firing ring
2. compression ring
3. scraping ring
4. articulated ring

3-25. What is the purpose of the bevelled top edge of a scraper ring?

1. To allow the ring to ride over the oil film
2. To push the oil film upward
3. To ensure the ring is installed right side up
4. To do all of the above

3-26. Why is it necessary to scrape around the top of a cylinder bore before pulling the piston?

1. To remove a metal ridge and carbon deposits
2. To increase clearance for the piston
3. To remove carbon and gum
4. To free the piston rings

3-27. To scrape the top of a cylinder bore before pulling the piston, you should use

1. a power grinder
2. a file
3. a metal scraper
4. emery paper

3-28. When using a brass drift to remove a frozen piston ring, you must

1. avoid breaking the ring
2. chisel through the ring
3. clean between the ring and land with a hacksaw
4. avoid damaging the land

3-29. With what, and where are piston ring gaps measured?

1. With a micrometer, on the piston
2. With a feeler gage, in the cylinder liner
3. With a feeler gage, in a vise
4. With a micrometer, in the cylinder

3-30. In addition to ring gap, what other factor must be measured to ensure correct ring fit?

1. Ring end gap
2. Ring-to-land gap
3. Ring width
4. Ring circumference

3-31. What two major forces act on the piston pin?

1. Side thrust and combustion pressure
2. Side thrust and rotating motion
3. Combustion pressure and crankshaft torque
4. Exhaust pressure and rotational force

3-32. What are the three classes of piston pins?

1. Rigid, stationary, and fixed
2. Free, semifloating, and full-floating
3. Semifloating, full-floating, and fixed
4. Full-floating, floating, and fixed

3-33. What is the classification of a piston pin that is clamped to the rod end?

1. Fixed
2. Semifloating
3. Either 1 or 2 above
4. Full-floating

3-34. Which of the following designs is NOT characteristic of full-floating piston pin bushings?

1. Bronze bearing surfaces
2. Shrink fits
3. No bearing in the rod end
4. Free to creep

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3-35. How do you measure the clearance between a piston pin and its bushing?

1. Use inside and outside micrometers
2. Use feeler gages
3. Take leads
4. Spot them with prussian blue

3-36. Which of these measures will help you remove a shrunk-fit bushing from a rod?

1. Heat the bushing
2. Grease the bushing
3. Use dry ice to cool the bushing
4. Do all of the above

3-37. When inserting new bushings, the three things you must check are

1. alignment, clearance, and appearance
2. cleanliness, appearance, and clearance
3. appearance, alignment, and cleanliness
4. cleanliness, alignment, and clearance

3-38. The connecting rods in an engine are used to

1. link two pistons
2. transfer piston motion to the crankshaft
3. locate the crankshaft in respect to the camshaft
4. link the piston pin to the piston

3-39. Which of the following types of engine uses two conventional connecting rods attached to a single crankpin?

1. Pancake engine
2. Single-acting in-line engine
3. Double-acting engine
4. V-type engine

3-40. What type of connecting rods do NOT need to have an eye at the piston end bored for the piston pin bushing?

1. Semifloating
2. Articulated
3. Fixed
4. Full-floating

3-41. What is the usual path of pressure lubricating oil to the piston pin?

1. From an oil spray, under the piston to the pin bushing
2. Through a hole in the crankshaft to a spray at the lower end of the rod
3. Through a hole in the crankshaft and through a hole in the rod to the pin
4. From a scoop on the bearing cap, through a hole in the rod, and to the pin

3-42. In terms of its shape, a crankshaft consists of

1. several flanges forged together
2. several offsets in a row
3. a shaft with a crank at the end
4. a series of bearings and weights

- In answering Items 43 through 46, refer to Figure 3A.

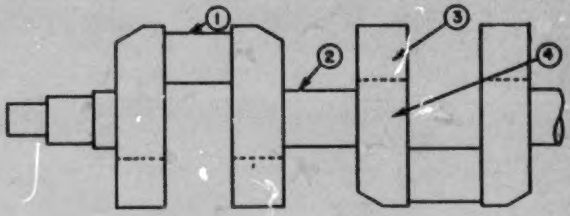

Figure 3A

Match the following parts with their locations in the figure.

3-43. Web

3-44. Main Bearing Journal

3-45. Connecting Rod Journal

3-46. Counterweight

3-47. The pulsations of the pistons against the crankshaft cause torsional vibrations. Which of the following devices reduce the damaging effect of these vibrations?

1. Torsional vibration dampers
2. Counterweights
3. Flywheels
4. All of the above

Learning Objective: Identify the parts, throw, and arrangement of the various crankshafts. Textbook pages 77 through 80.

3-48. What is the function of the drilled passages in the crankshaft?

1. To relieve excess oil pressures at the connecting rods
2. To carry oil to the connecting rods
3. To drain off oil that collects underneath piston heads
4. To lighten the crankshaft by an amount that offsets the weight of any counterbalance used

3-49. Why are the passages drilled so two holes are in each journal?

1. To give twice the oil flow
2. In case one hole gets clogged the other will still work
3. To give constant flow regardless of crank position
4. To provide more oil pressure to the connecting rod

3-50. After passing through the crankshaft, oil travels through the

1. main bearings and the connecting rod
2. connecting rod bearing and the piston pin
3. connecting rod bearing and the connecting rod
4. connecting rod and piston crown

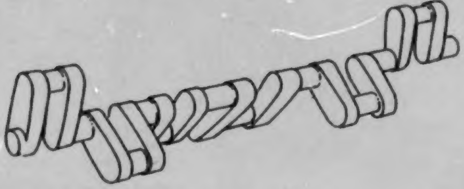

Figure 3B

3-51. The crankshaft in the figure could be used in which of the following engines?

1. 6-cylinder, 2-stroke cycle engine
2. 6-cylinder, 4-stroke cycle engine
3. Either of the above
4. 12-cylinder, in-line engine

Learning Objective: Identify the different types of camshafts and point out their metallurgical makeup. Textbook pages 80 and 81.

3-52. What is the usual metallurgical makeup of camshaft surfaces?

1. Case-hardened low-carbon alloy steel
2. Ground tempered steel
3. Annealed high-carbon steel
4. Chrome-plated alloy steel

3-53. The rate and amount of valve lift are determined by

1. the size of the cams
2. cam timing
3. the number of cams
4. the shape of the cams

Learning Objective: Point out or identify the different types of journal bearings. Explain how to check bearing wear and replace worn bearings as well as repair shafts. Textbook pages 81 through 87.

3-54. What is "Satco"?

1. A bronze-backed bearing
2. A trimetal bearing
3. A lead-based bearing material
4. A journal bearing

3-55. What bearing metal is used in a trimetal bearing?

1. Lead
2. Babbitt
3. Bronze
4. Steel

3-56. What is the primary purpose of the coating metal on copper-lead bearings?

1. To harden the journal surfaces
2. To harden the bearing surface
3. To reduce friction
4. To reduce corrosion

3-57. A bearing material made of aluminum is alloyed with

1. tin
2. copper
3. lead
4. bronze

3-58. When small engine bearings have worn to excessive clearance, what is usually done?

1. Shims are removed
2. The bearings are replaced
3. The caps are filed
4. Spacers are added

3-59. In main bearing shells, where are the oil distribution grooves located?

1. Around the caps
2. At the sides
3. Where shaft pressure is the least
4. All around the bearing

3-60. What portions of the piston pin and connecting rod bearings of a 2-stroke cycle engine carry the load?

1. Lower halves of both bearings
2. Upper halves of both bearings
3. Lower half of the piston pin bearing and the upper half of the connecting rod bearing
4. Upper half of the piston pin bearing and the lower half of the connecting rod bearing

3-61. Impending bearing failures may be indicated by

1. lower than normal lubricating oil pressure and temperature
2. higher than normal lubricating oil pressure and temperature
3. lower than normal lube oil pressure and higher than normal lube oil temperature
4. higher than normal lube oil pressure and lower than normal lube oil temperature

3-62. The recommended corrective action for journal bearings that have small raised surfaces or minor pits is to

1. replace the bearings
2. stone down the raised surfaces and fill in pits with solder
3. grind the surfaces with a hand grinder
4. smooth down the surfaces with a bearing scraper

3-63. Before installing new or restored bearings, what should you do?

1. Wipe oil on the journal surfaces
2. Wipe oil on the bearing surfaces
3. Both of the above
4. Clean the bearings with solvent and wipe dry

3-64. Certain information is indicated by markings placed on each half of connecting rod bearings when they are removed from an engine. These markings ensure that the halves will be installed in their original positions. Which of the following is an example of sufficient and necessary information being shown by a marking?

1. No. 2 cylinder
2. No. 2 cylinder, upper half
3. No. 2 cylinder, engine No. 311645
4. Upper half, engine No. 311645

3-65. What procedures are acceptable for tightening connecting rod bolts?

1. Bolt elongation and bearing cap compression
2. Bearing cap compression and tightening with a slugging wrench
3. Torque wrench tightening and bolt elongation
4. Slugging wrench tightening and using a wrench extender

3-66. Which of the following procedures can be used to give a direct reading of connecting rod bearing clearance?

1. Bridge gage readings
2. Plastigage
3. Leads
4. Bearing shell thickness readings

3-67. What method is used to determine if a connecting rod or main bearing journal is out-of-round?

1. A bridge gage reading
2. Several micrometer readings
3. Several plastigage readings
4. A dial indicator reading

3-68. What is done with a crankshaft journal which is scored and has turned blue in some spots?

1. The crankshaft is replaced
2. The crankshaft is annealed and reground
3. The journal is ground down to remove the scoring and the blue areas
4. The scoring is stoned and the surface dressed with crocus cloth

3-69. To avoid further engine damage when repairing minor scoring in a crankshaft journal, you should

1. work quickly
2. case harden the surface when finished
3. dress both the bearing and the journal
4. keep abrasives out of the oil passages

3-70. What instrument is used to take crank web deflection readings?

1. A feeler gage
2. An outside micrometer
3. A strain gage
4. A gage block

3-71. In some engines, crank web deflection readings are NOT taken with the piston at bottom dead center. Why?

1. The crank does not deflect at that point
2. There are no prick punch marks there
3. The gage is upside down at that point
4. The connecting rod is in the way

3-72. How should you insert a camshaft into the camshaft recess?

1. Rotate it as you push it in
2. Shake it up and down
3. Apply grease to it
4. Hit it with a sledge

Learning Objective: Explain the functions of flywheels and jacking gear. Textbook pages 87 through 89.

3-73. Assuming that the moving parts attached to the crankshaft of each of the following engine types are of equal mass, which type of engine will probably use the lightest flywheel to stabilize crankshaft rotation?

1. 6-cylinder, in-line, 2-stroke cycle
2. 6-cylinder, in-line, 4-stroke cycle
3. 8-cylinder, in-line, 2-stroke cycle
4. 12-cylinder, V, 4-stroke cycle

3-74. On smaller diesel engines, what is the function of the turning gears?

1. To start the engine
2. To reverse the engine
3. To do both of the above
4. To position the crankshaft for maintenance and tests

3-75. In starting a Fairbanks-Morse engine, the jacking device must be

1. locked out of mesh with the flywheel
2. operated by an air motor wrench
3. vigorously hand cranked
4. removed

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Assignment 4

Engine Operating Mechanisms; Diesel Engine Air Systems; and Engine Starting Systems

Textbook Assignment: Pages 93 through 136

Learning Objective: Identify the functions of the operating functions of crankshaft, camshaft, actuating mechanisms, and cam follower of a 2-stroke cycle in-line diesel. Textbook pages 93 - 94.

4-1. What is the term for the group of parts that takes power from the crankshaft and transmits that power to various engine components and accessories?

1. Actuating mechanism
2. Drive mechanism
3. Camshaft assembly
4. Power takeoff unit

4-2. In transmitting power within an engine, a drive mechanism will do all but which of the following?

1. Change the direction of motion
2. Change the speed of motion
3. Change rotary to reciprocating motion
4. Transfer motion in the same direction

4-3. What is the speed of the camshaft in a 2-stroke cycle engine when the crankshaft is turning at 1100 rpm?

1. 1100 rpm
2. 550 rpm
3. 2200 rpm
4. 1650 rpm

4-4. The combination of parts which receives power from the drive mechanism and transmits the power to the engine valves is called a/an

1. gear mechanism
2. accessory drive mechanism
3. actuating mechanism
4. timing mechanism

4-5. A valve actuating mechanism does NOT necessarily include which of the following parts?

1. Push rods
2. Cams
3. Valve springs
4. Cam followers

4-6. When an engine is NOT equipped with push rods, the cam follower is a part of the

1. rocker arm
2. valve bridge
3. camshaft
4. connecting rod

Learning Objective: Identify the operating functions of gears, shafts, and rocker arms of a GM 71 series diesel engine. Textbook pages 94 - 98.

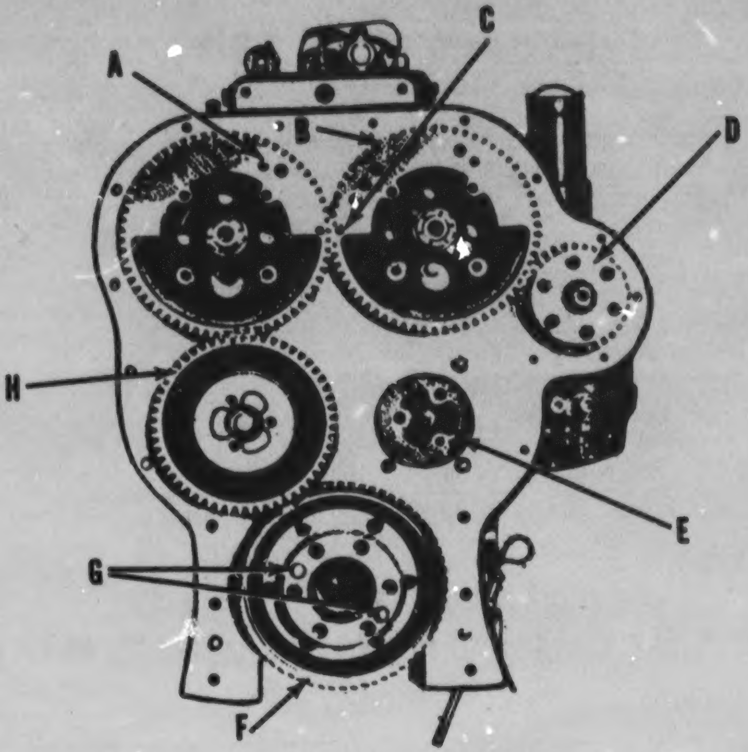

Figure 4A.- Gear Train of GM 6-71 engine.

4-7. In a GM 71, which gear in figure 4A transmits power to operate the fuel pump?

1. A
2. B
3. D
4. E

4-8. Which gear in figure 4A operates the mechanism that actuates the fuel injectors?

1. B
2. F
3. D
4. H

4-9. Which gear in figure 4A stabilizes the oscillating impulses of the engine?

1. A
2. E
3. F
4. H

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4-10. The fuel oil pump on the GM 6-71 diesel engine is driven by the

1. valve actuating gear
2. governor drive shaft
3. lower blower rotor shaft
4. upper blower rotor shaft

4-11. On a GM 6-71 diesel engine, where is the water pump mounted and to what accessory gear is it connected?

1. Left side of the front end plate and connected to the idler gear shaft
2. Right side of the engine block and connected to the main drive shaft
3. Front end of the governor housing and connected to the governor drive shaft
4. Front end of the blower and connected to the blower rotor shaft through a coupling

4-12. The fuel injectors on a GM 6-71 diesel engine are actuated by the

1. hydraulic lifters
2. valve bridge
3. rocker arms
4. camshaft lobes

Learning Objective: Identify the parts driven by the accessory drive of the GM-278A series diesel engine. Textbook pages 99 - 101.

4-13. What parts of the GM-278A diesel engine are driven by the accessory drive?

1. Cam followers and rocker arms
2. Blower and water pumps
3. Fuel injectors
4. Starting air timing valve and the governor

4-14. In a GM-278A diesel engine, the lubricating oil pump receives power from the

1. accessory drive
2. blower drive
3. camshaft drive
4. camshaft gear through a flexible coupling

4-15. In a GM-278A diesel engine, what keeps the tension off the valve stems until the bridge is actuated by the rocker arm?

1. Valve bridge
2. Rocker arm
3. Valve bridge spring
4. Cam action

Learning Objective: Identify the gears, shafts, and mechanisms within the Fairbanks-Morse 38D. Textbook pages 101 through 105.

4-16. In the Fairbanks-Morse opposed-piston engine, which type of drive operates the fuel injection mechanism?

1. Gear type
2. Chain type
3. Belt type
4. Spur type

4-17. In an FM 38D diesel engine, the camshaft operates the

1. exhaust valves
2. governor
3. timing gear assembly
4. tappet assembly for the fuel injection pumps

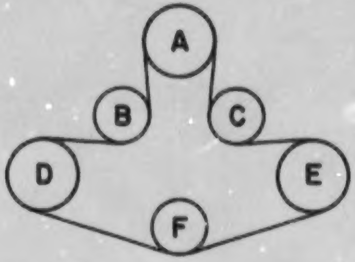

Figure 4B.--Chain assembly of FM 38D engine.

4-18. Which sprockets in Figure 4B do NOT transmit power?

1. A, B, and C
2. B, C, and D
3. B, C, and F
4. D, E, and F

4-19. Which sprocket in figure 4B is attached to the shaft that provides power to drive the engine's blower?

1. A
2. B
3. D
4. F

4-20. The majority of the accessories for the FM 38D are driven by a gear mechanism which receives power from the

1. upper crankshaft
2. lower crankshaft
3. camshaft drive
4. chain assembly

4-21. On a FM 38D, the shaft of the lubricating oil pump drive transmits power to drive the

1. fuel pump
2. water pump
3. governor
4. injector pump

Learning Objective: Describe the speed ratio of the camshaft and crankshaft as well as the source of power for the turbocharger and explain why helical gears are used with the 4-stroke cycle diesel engine. Textbook pages 106 through 108.

4-22. In a 4-stroke cycle diesel engine, the turbocharger is driven by

1. a gear train
2. a change drive
3. an actuating gear
4. exhaust gases

4-23. In a 4-stroke cycle diesel engine, the camshaft turns at what speed in relation to the crankshaft?

1. Same speed as the crankshaft
2. One-half the speed of the crankshaft
3. Twice the speed of the crankshaft
4. Varies with engine design

4-24. In the camshaft drive of a 4-stroke cycle diesel engine, why are helical teeth gears frequently used?

1. Helical teeth gears are cheaper
2. Helical teeth gears are quieter and provide more transmission of power
3. Helical teeth gears never wear out
4. Helical teeth gears are simple to time and install

Learning Objective: Identify scavenging and supercharging components by their functions and relationship to the intake and exhaust systems. Textbook pages 109 through 114.

4-25. In the intake system of late model 2-stroke diesel engines, a blower is used to force

1. air into the cylinders
2. air through the cylinder jacket
3. fuel through the fuel injectors
4. exhaust gases from the exhaust manifold

4-26. In a 2-stroke cycle diesel engine, the openings through which air enters the cylinders are referred to as

1. access vents
2. accumulator valves
3. baffle holes
4. scavenge ports

4-27. Scavenging in a 2-stroke cycle engine takes place during the early part of the downstroke and the latter part of the upstroke.

4-28. In the 4-stroke cycle diesel engine, the overlap between the intake and the exhaust permits air from the blower to sweep exhaust gases from the cylinder and also to

1. clean oil drain passages
2. cool some of the engine parts
3. eject foul air from the air box
4. force air through the turbine

4-29. In a naturally aspirated engine, the air is forced into the cylinders because of the

1. greater pressure outside the cylinder
2. blower pressure
3. turbocharger pressure
4. piston as it moves toward the combustion space during the exhaust event

4-30. In addition to clearing the cylinders of exhaust gases, the air that enters the cylinders can be used to

1. increase the power output of the engine
2. clear foul air from the lubricating oil sump
3. clean the spray tip of the fuel injectors
4. preheat the diesel fuel

4-31. Scavenging is the removal of exhaust gas with the exhaust ports closed.

4-32. In the supercharged 4-stroke cycle engine, why is there an overlap of the intake and exhaust events?

1. To remove exhaust gases with blower pressure
2. To increase power
3. To do both 1 and 2 above
4. because of the 720° it takes to complete a cycle

4-33. The crankshaft of a 4-stroke cycle engine makes four complete revolutions per cycle.

- Items 4-34 through 4-38 are concerned with a supercharged Cooper-Bessemer 4-stroke cycle diesel engine.

4-34. The intake and the exhaust valves are open longer than they are on a comparative engine without a supercharger. This permits a longer

1. compression event
2. power event
3. scavenging event
4. injection event

4-35. How many degrees of crankshaft rotation before the piston reaches BDC does the exhaust valve open?

1. 45°
2. 55°
3. 75°
4. 85°

4-36. How many degrees of crankshaft rotation before the piston reaches TDC does the turbocharger begin to force air into the cylinder?

1. 45°
2. 55°
3. 75°
4. 85°

4-37. What is the cylinder pressure by the time intake valves close?

1. 1 to 3 psi
2. 3 to 5 psi
3. 5 to 8 psi
4. 8 to 10 psi

4-38. In a 4-stroke cycle engine, a complete cycle of events has occurred after the crankshaft has completed

1. one revolution
2. one revolution and each piston has made two strokes
3. two revolutions and each piston has made two strokes
4. two revolutions and each piston has made four strokes

4-39. Supercharging takes place in a 4-stroke cycle engine when the piston is in the vicinity of

1. TDC
2. BDC
3. the injection center
4. the combustion center

4-40. In a 2-stroke cycle diesel engine with a supercharger, how many degrees of crankshaft rotation past TDC does the power event force the piston through the downstroke?

1. 17 1/2°
2. 48°
3. 71°
4. 92 1/2°

4-41. In a 2-stroke cycle engine, how many degrees of rotation are involved in the scavenging operation?

1. 44 1/2°
2. 92 1/2°
3. 132°
4. 160°

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Learning Objective: List the intake system components by their function. Textbook pages 114 - 125.

4-42. In figure 6-3B of the textbook, how many degrees of the crankshaft rotation are used in injection?

1. 5°
2. 17 1/2°
3. 92 1/2°
4. 96°

4-43. In a dry-type diesel engine air intake system, in what order does air pass through the system?

1. Silencer, screen, blower
2. Silencer, blower, screen
3. Screen, silencer, blower
4. Screen, blower, silencer

4-44. In GM-71 diesel engines, what material serves as the cleaning element in the viscous type of silencer-and-cleaner assemblies?

1. Cotton waste
2. Wire screen
3. Metal wool
4. Corrugated paper

4-45. The primary function of the blower of a supercharged engine is to force

1. scavenging air through the cylinders
2. a large volume of low-pressure air into the cylinders
3. a large volume of high-pressure air into the cylinders
4. a small volume of high-pressure air into the cylinders

4-46. To which of the following types of blowers does the Roots blower belong?

1. Centrifugal
2. Positive-displacement
3. Axial flow
4. Rotary vane

4-47. In the GM 16-278A diesel engine, how many lobes are on each rotor of a Roots blower?

1. Six
2. Two
3. Three
4. Four

4-48. The turbine of a turbocharger is driven by the

1. exhaust gases
2. engine crankshaft
3. air from the impeller
4. blower and accessory drive mechanism

4-49. In an Elliot-Buchi turbocharger, the speed of the turbine is regulated by the

1. camshaft gear speed
2. size of the exhaust outlet
3. direction of engine rotation
4. load and speed of the engine

4-50. The air forced into the cylinders by a turbocharger is often reduced in volume by

1. an air compressor
2. an aftercooler
3. a diffuser
4. a forced-draft blower

4-51. The temperature of the air entering a diesel engine must be kept low to aid in cooling the

1. turbine
2. turbine and exhaust valves
3. cylinders
4. exhaust valves and exhaust manifold

4-52. In a 2-stroke cycle engine, the intake passage that conducts air to the cylinders is usually called

1. an air box
2. an air tunnel
3. a rotor housing
4. a venturi

4-53. In a 4-stroke cycle diesel engine, the admission of air into the cylinder is usually regulated by

1. a manifold
2. an air silencer
3. air headers
4. cylinder valves

4-54. On some large diesel engines, the test valve for each cylinder is used to perform which of the following functions?

1. To relieve the cylinder pressure when the engine is turned by hand
2. To remove oil or water from the cylinder
3. To test firing pressure and compression
4. To do all of the above

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4-55. Some diesel engines have spring-loaded poppet type valves provided for each cylinder. The function of the valves is to

1. permit the connecting of a pressure indicator
2. force scavenging air into the headers
3. open at a predetermined cylinder pressure
4. permit a portion of the gases to be collected for testing

Learning Objective: Explain the purpose of the exhaust manifold, pyrometers, piping and silencers. Textbook pages 125 through 128.

4-56. The exhaust system of a diesel engine may be designed to perform which of the following functions?

1. Quenching sparks
2. Muffling exhaust noise
3. Removing solids from exhaust gases
4. All of the above

4-57. In figure 6-19 of the textbook, after the exhaust gases leave the cylinders, they pass through the

1. exhaust pipe
2. exhaust silencer
3. overboard discharge pipe
4. turbine end of the turbocharger

4-58. A pyrometer is used on diesel engines for measuring

1. exhaust temperatures
2. ignition quality of fuel
3. cylinder compression
4. temperature difference between the intake and exhaust manifolds

4-59. In the wet-type muffler, how does the water cause a reduction in noise?

1. It causes the gases to expand
2. It causes the gases to contract
3. It washes the gases
4. It quenches all sparks

Learning Objective: Describe the operating principles of starting systems and list the different types of similarities, differences, and functions. Textbook pages 129 through 136.

4-60. To keep a starting motor from overheating, you must be sure to

1. let it cool for 2 or 3 minutes after running it as long as 30 seconds
2. let it cool for 30 seconds after running it as long as 2 or 3 minutes
3. let it cool for 1 minute after running it as long as 1 minute
4. disengage it as soon as the engine starts

4-61. What is the usual gear ratio between the standard drive pinion and the engine flywheel of a diesel engine?

1. 5 to 1
2. 10 to 1
3. 15 to 1
4. 20 to 1

4-62. The starter pinion must be disengaged from the flywheel as soon as the engine starts because the

1. starter will have a braking effect
2. high speed which is developed by the engine would cause damage to the starting motor
3. starter will begin to act like a governor
4. flywheel gears may break

4-63. The magnetic switch on engines using the Bendix drive is grounded to the

1. engine cylinder block
2. generator housing
3. starting motor housing
4. engine base

4-64. Which of the following precautions should be taken before re-engaging the Bendix drive starter?

1. Put the starter control switch on "low"
2. Wait until the engine has stopped
3. Disconnect the starting motor battery
4. Tighten the drive spring

4-65. After the engine starts, the pinion of the Dyer switch drive mechanism is locked in the demeshed position by the

1. pinion guide
2. pinion stop
3. shift lever
4. pinion spring

4-66. To which of the following positions must the Dyer shift drive mechanism be returned before the pinion can be re-engaged?

1. Disengaged position
2. Beginning engagement
3. Fully engaged
4. Starting position

● The generator's charging current must equal the battery's discharge rate EXCEPT when the starter motor is being used. The generator does not supply current when the starter is being operated because the engine's speed is too slow for the operating speed of the generator and the starter motor would overload the generator.

4-67. If the generator fails to generate, and the running lights are burning, what, if anything, will happen to the battery?

1. The generator will short circuit the battery
2. The battery will discharge
3. The battery acid will get stronger
4. Nothing

4-68. What controls the output voltage of an alternator?

1. Solenoid
2. Rectifier
3. Speed of the engine
4. Voltage regulator

4-69. What controls the output voltage of a d.c. generator?

1. Solenoid
2. Rectifier
3. Speed of engine
4. Voltage regulator

4-70. What is/are the function(s) of the voltage regulator associated with a d.c. battery-charging generator?

1. To prevent the generator from exceeding its rated output voltage
2. To prevent the generator from overcharging the battery
3. To prevent the flow of current from battery to generator when the generator's output voltage is less than the battery's
4. To prevent all of the above from happening

4-71. Which of the following solvents may be used to clean generators?

1. Alcohol
2. Inhibited methyl chloroform
3. Benzine
4. Gasoline

4-72. Excess grease will lead to bearing failure.

4-73. What should be the color of a clean commutator that has been used for 2 weeks or more?

1. Dark brown
2. Blue
3. Black
4. Copper

4-74. The hydraulic starting motor is operated by hydraulic pressure from the

1. accumulator
2. hand pump
3. engine-driven pump
4. reservoir

4-75. The compressed air for starting a supercharged GM diesel engine is admitted into

1. the cylinders
2. an air-driven starting motor
3. the supercharger
4. the exhaust manifold

Assignment 5

Engine Starting Systems (Continued) and Engine Cooling Systems

Textbook Assignment: Pages 136 through 176

Learning Objective: Describe the operating principles of starting systems and list the different types of similarities, differences and functions. Textbook pages 136 through 143.

5-1. In figure 7-11 of the textbook, what is the number of the rotating member?

1. 1
2. 2
3. 3
4. 4

5-2. A safe pressure for air-starting diesel engines is assured through the use of a

1. reducing valve and a relief valve
2. relief valve and a governor
3. governor and a reducing valve
4. reducing valve, a relief valve, and a governor

5-3. During the starting cycle the pressure regulator valve rapidly adjusts to regulate starting pressure. What is the valve position when the pressure in the dome is equal to the pressure under the diaphragm?

1. Fully open
2. Fully closed
3. One-half open
4. Almost closed

5-4. In the pressure regulator, what will happen if the air screen becomes clogged with dirt?

1. The relief valve will lift
2. The bypass will operate
3. The regulator valve will close
4. The screen will be forced into the valve body

5-5. Which cylinders in a 16-cylinder engine are air-started?

1. 4 in each bank
2. 6 in one bank, 2 in the other
3. 8 in one bank, none in the other
4. 6 in each bank

5-6. The air-starting control valve on a GM diesel engine is opened by

1. a collapsing spring
2. a hand lever
3. the camshaft lobes
4. air pressure

5-7. In starting a diesel, the major objective is to attain compression rations sufficient to

1. turn the flywheel
2. ignite the fuel
3. reduce the friction
4. overcome the inertia

5-8. The construction of a GM starting air distributor valve differs from the construction of a GM air starting check valve in that the distributor valve has a

1. poppet type valve
2. seat which is part of the valve body
3. cam follower to serve as the valve guide
4. spring to exert closing pressure

5-9. In the air starting check valve when the distributor valve is closed, what closes the check valve?

1. Air pressure in the valve chamber
2. Spring pressure
3. Air pressure in the combustion chamber
4. Exhaust pressure

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Learning Objective: Name the different types of ignition aids and give the purpose of each. Textbook pages 143 through 145.

5-10. When a diesel engine is turned over slowly during the starting operation, the injected fuel will probably not ignite because of the

1. low air temperature in the cylinder
2. high cylinder pressure
3. oil loss from around the pistons
4. airflow into the carburetor

5-11. In the ether capsule primer type of ignition aid, the liquid ether is contained in the

1. discharger cell
2. discharger nozzle
3. pressure primer bulb
4. 3/16-inch tubing

5-12. In using the ether capsule primer, when is the starter switch released if the engine does not start?

1. After 30 seconds
2. 15 seconds after the engine has come up to cranking speed
3. After 15 seconds
4. After 20 seconds

5-13. In using the pressurized cylinder starting aid, how long should the remote control knob be held open?

1. 1 to 2 seconds
2. 15 seconds
3. 20 seconds
4. 30 seconds

5-14. The flame primer has two assemblies. Which of the following parts make up the heater unit?

1. Burner, pressure pump, and ignition aid
2. Pressure pump, ignition coil and ignition switch
3. Burner, ignition coil and vibrator
4. Vibrator, burner and pressure pump

5-15. In the flame primer operation, the ignition switch is operated simultaneously with what other component(s)?

1. The hand pump
2. The starter switch
3. Both 1 and 2
4. The choke

Learning Objective: Explain the purpose of engine cooling systems. Textbook page 146.

5-16. Approximately 30% to 35% of the heat of combustion must be removed to prevent damage to engine parts. Which of the following cooling mediums removes the greater portion of the heat generated by combustion?

1. Air
2. Water
3. Oil
4. Fuel

5-17. When engine temperature exceeds a specified level, the viscosity of the lubricating oil will

1. increase
2. decrease
3. remain unchanged
4. oxidize

5-18. In a diesel engine, what will happen to the lubricating oil if the engine is operated at too low a temperature?

1. The oil will oxidize
2. The oil will break down
3. Acids and sludge will form in the oil
4. The viscosity of the oil will decrease

Learning Objective: Compare the characteristics of open and closed marine cooling systems. Textbook pages 147 to 149.

5-19. Most marine engine installations are cooled directly by

1. saltwater
2. freshwater or antifreeze
3. air
4. oil

5-20. The open cooling system is subjected to which of the following conditions?

1. Formation of scale in the engine
2. Marine growth in the piping
3. Fluctuating seawater temperature
4. All of the above

5-21. The closed cooling systems of automobile engines and marine engines differ with respect to their

1. method of circulating the coolant
2. use of freshwater as a coolant
3. method used to carry away the heat
4. continuous reuse of the freshwater

Learning Objective: Identify and describe the components of a marine engine cooling system. Textbook pages 149 through 168.

5-22. Which of the following pumps are the principal types used in engine cooling systems?

1. Centrifugal and gear
2. Centrifugal and jet
3. Centrifugal and 2-stage piston
4. Centrifugal and axial piston

5-23. In what type of pump is water drawn into the center of the impeller and thrown at a high velocity into the casing surrounding the impeller?

1. Gear pump
2. Rotary-type pump
3. Screw pump
4. Centrifugal pump

5-24. In internal-combustion engines, heat exchangers are used primarily for

1. heating fluids
2. cooling fluids
3. heating gases
4. cooling gases

5-25. Engine coolers may be classified in several ways; coolers used in cooling systems of engines are commonly identified on the basis of

1. relative direction of flow
2. the number of passes
3. the path of heat
4. construction features

5-26. In a given engine installation, coolers used to cool lubricating oil are smaller than those used to cool water.

5-27. In the shell-and-tube cooler, what is the purpose of the floating tube sheet?

1. To prevent leakage of the tube bundles
2. For easy removal of the tube bundles
3. To allow for expansion of the tube bundle
4. To ensure maximum cooling effect

5-28. In a shell-and-tube cooler, why are transverse baffles arranged around the tube bundle?

1. For maximum cooling effect and to support the tube bank
2. To decrease pressure and support the tube bank
3. To decrease pressure, increase volume, and support the tube bank
4. To increase pressure, decrease volume, and support the tube bank

5-29. One important advantage of the strut-tube cooler over the shell-and-tube cooler is that the strut-tube cooler

1. takes less current to operate than the shell-and-tube cooler
2. withstands a higher degree of scaling and larger foreign particles without clogging than does the shell-and-tube cooler
3. is more compact than the shell-and-tube cooler
4. is more durable than the shell-and-tube cooler

5-30. What type of cooler is used only for cooling oil?

1. Shell-and-tube
2. Strut-tube
3. Plate-tube
4. Coil-tube

5-31. In a plate-tube cooler, the cooling liquid flows through the tubes.

5-32. Which of the following coolers is used to cool air between the turbocharger and intake manifold?

1. Intercooler
2. Aftercooler
3. Oil cooler
4. Water cooler

5-33. The coolant in the cooling system of a GM 16-278A engine flows from the cylinder head passages to the

1. cylinder liner passages
2. exhaust elbow and manifold water jackets
3. freshwater cooler
4. freshwater manifolds

5-34. In a 38D8 1/8 engine, the last passage in the engine through which water flows before it goes through the cooler is the

1. liner passages
2. head passage
3. exhaust elbows
4. water header

5-35. What component of an engine cooling system stores water for re-entry into the system when the water supply decreases on account of leakage?

1. Freshwater pump
2. Expansion tank
3. Exhaust-manifold
4. Engine jacket

5-36. Which of the following is/are a function(s) of the expansion tank?

1. To pressurize the system
2. To vent the system to the atmosphere
3. To condense steam that forms in the system
4. To do both 2 and 3 above

5-37. Which of the following devices prevents the entrance of seaweed and other debris into the seawater circuit?

1. Scoops
2. Filters
3. Strainers
4. Bypass basket

5-38. Which of the following is one of the principal factors affecting the proper cooling of an engine?

1. Type of cooling fluid used
2. Type of pump circulating the cooling fluid
3. Rate of flow of the cooling fluid
4. Ambient temperature

5-39. High water velocity is undesirable in a cooling system because

1. it causes hot spots
2. it causes scale
3. it causes heat to be carried away too slowly
4. it causes scouring of metal surfaces

5-40. As the velocity of the circulating fluid is reduced, the temperature of the cooling fluid will

1. increase
2. decrease
3. be unchanged
4. increase or decrease depending on engine load

5-41. How is the temperature of engine cooling water controlled?

1. By regulating the amount of water discharged into the engine
2. By regulating amount of water which passes through the freshwater cooler
3. By both 1 and 2 above
4. All cooling water temperature is controlled with a thermostat

5-42. Throttling valves are used only to provide a constant flow of seawater or to close the circuit completely when the freshwater circuit incorporates a thermostat.

5-43. Which of the following types of thermostatic valves are used in the cooling systems of modern marine engines?

1. Manual and throttling
2. Conventional and three-way proportioning
3. Throttling and pump discharge
4. Manual and two-way proportioning

5-44. In the cooling system of a diesel engine, what causes the conventional-type thermostatic valve to open?

1. A decrease in the circulating freshwater temperature
2. An increase in the circulating freshwater temperature
3. An increase in the fuel oil temperature
4. A decrease in the fuel oil temperature

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5-45. In the freshwater system of an engine, how does the automatic regulating valve maintain the freshwater temperature at any desired value?

1. By bypassing a portion of the water around the lube oil cooler
2. By bypassing a portion of the water around the saltwater cooler
3. By bypassing a portion of the water around the freshwater cooler
4. By bypassing a portion of the oil around the saltwater cooler

5-46. In the temperature-control element of an automatic regulating valve, the vapor pressure is balanced by the

1. sealed bellows and cap
2. ether and alcohol mixture
3. shims attached to the valve stem
4. coil spring

5-47. The bulbs which cause cooling water regulators to operate are always located in the saltwater discharge line of the engine.

5-48. In an installation where seawater controls the lubricating oil temperature, how many temperature regulators are there, and in what system or systems are they installed?

1. Three; two in the seawater circuit and one in the freshwater circuit
2. Two; one each in the fresh- and seawater circuits
3. Two; both in the seawater circuit
4. Two; one in the lubricating oil system and one in the seawater circuit

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Learning Objective: Explain and describe key points and considerations in operating and maintaining cooling systems. Textbook pages 168 through 176.

5-49. Lubricating oil and freshwater coolers should be inspected periodically every

1. 10 - 20 days
2. 15 - 40 days
3. 20 - 50 days
4. 30 - 60 days

5-50. In the closed cooling system of a marine engine, the gradual increase of temperature of the lubricating oil and the freshwater may be an indication of

1. excessive pressure in the system
2. too small a cooler for the installation
3. scale buildup on the cooler tubes
4. a ruptured tube within the cooler

5-51. With an engine operating under normal load the seawater discharge temperature should be maintained below a maximum of

1. 130°F
2. 140°F
3. 150°F
4. 160°F

5-52. Turning down the grease cups too often on a seawater pump may finally result in the accumulation of grease on the cooler element, thus reducing its cooling capacity.

5-53. What is ordinarily used to clean the saltwater side of a shell-and-tube oil cooler?

1. Boiler compound
2. Acid solution
3. Scrapers and wire brushes
4. Water and air lances

5-54. What should you use to clean the oil side of a strut-tube type cooler?

1. Scrapers
2. Chemicals
3. Hot water lances
4. Jets of steam

5-55. Which of the following conditions will indicate a leak in the tubes of an oil cooler?

1. Water in the lube oil
2. Oil slicks in the cooling water
3. An apparent increase in the amount of lube oil in the engine sump
4. All of the above

5-56. Which of the following conditions will most likely occur if a cooler is operated above the maximum pressure indicated on the nameplate?

1. Scaling
2. Corrosion
3. Leaks
4. Bubbles

5-57. Which of the following practices helps prevent the formation of scale within the cooling system?

1. Using distilled water in the cooling system
2. Using water with zero hardness
3. Maintaining the chloride concentration within specified limits
4. Any of the above

5-58. In the closed cooling system of an engine, which of the following conditions or elements forms scale on the hot surfaces?

1. Sodium chromate
2. Hot spots
3. Magnesium and calcium
4. Chloride

5-59. A pH value of 6 denotes a solution that is

1. slightly alkaline
2. slightly acid
3. completely neutral
4. sometimes acid and sometimes alkaline

Sample	pH Value	Concentration	
		Chromate	Chloride
A	8	800 ppm	110 ppm
B	8.5	800 ppm	80 ppm
C	9.5	1800 ppm	90 ppm
D	10	1500 ppm	50 ppm

Figure 5A.-Test results of four samples of treated water.

5-60. Which test sample in figure 5A meets all the specified limits for treated water intended for use in an engine cooling system?

1. A
2. B
3. C
4. D

- Sodium dichromate and boiler compound treatment is no longer authorized for Navy use.

5-61. In conducting colorimetric tests for alkalinity and chromate concentration of water in engine cooling systems, which source of artificial light is recommended?

1. Arc lamp
2. Flashlight
3. Incandescent lamp
4. Daylight fluorescent lamp

5-62. A test sample of engine cooling water that appears yellower than the color disk standards for alkalinity as well as those for chromate concentration has a

1. low pH value and a high chromate concentration
2. low pH value and a low chromate concentration
3. high pH value and a low chromate concentration
4. high pH value and a high chromate concentration

5-63. You are testing the chloride concentration in engine cooling water, starting with a test sample that has the characteristic yellow color of chromate. After one chloride test tablet is dissolved completely in the sample, what will be the color of the sample if its chloride content is below 100 ppm?

1. Yellow
2. Bluish-green
3. Reddish-brown
4. Yellowish-green

5-64. While treating engine cooling water you accidentally spill some sodium chromate on your hands. What should you do first?

1. Immerse your hands in oil
2. Wash your hands with plenty of soap and water
3. Apply a light coating of vaseline to your hands
4. Immerse your hands in a solution of sodium bicarbonate and water

5-65. What is installed between the potable freshwater supply and fill connection to prevent contamination?

1. Check valve
2. Globe valve
3. Air gap
4. Gate valve

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Assignment 6

Engine Lubricating Oil Systems

Textbook Assignment: Pages 177 through 204

Learning Objective: Point out three functions of lubricating oil. Textbook pages 177 and 178.

6-1. For efficient engine operation, how should the lubricant be supplied to the engine parts?

1. At high pressure
2. At minimal pressure
3. At flashpoint
4. At proper temperature

6-2. In the contacting surfaces of moving engine parts, which of the following materials will reduce friction?

1. Water
2. Compressed air
3. Clean film of oil
4. Each of the above

6-3. If the engine temperature exceeds the maximum limit during operation, the proper lubricant will prevent damage.

6-4. The lube oil used in an engine must perform what function(s)?

1. Form a seal between the piston rings and cylinder wall
2. Aid in heat transfer
3. Clean the engine
4. All of the above

6-5. Which of the following engine problems will most likely be caused by an insufficient oil film between the connecting rod bearings and the crank journals?

1. Seized piston
2. Wiped bearings
3. Both 1 and 2 above
4. Cracked cylinder

6-6. The stability of an oil describes the ability of the oil to resist

1. oxidation and deterioration
2. viscosity change
3. emulsification
4. flashpoint change

6-7. Sludge in the lubricating oil of an engine can cause engine breakdown.

Learning Objective: Point out characteristics and tests of oil used by the Navy. Textbook pages 178 through 184.

6-8. To select the proper lube oil for use in an engine, you must know the viscosity at

1. 122°F
2. 140°F
3. 200°F
4. operating temperature

6-9. To determine the viscosity of a fuel oil, what instrument should you use?

1. Saybolt Universal viscosimeter
2. Visgage
3. Saybolt Furol viscosimeter
4. Trial tube

6-10. What is the standard temperature used for testing a lubricating oil for viscosity?

1. 122°F
2. 130°F
3. 210°F
4. Either 2 or 3 above depending on the class of oil

6-11. As a lube oil is used in a running engine, which, if any, of the following effects on viscosity should you expect?

1. A change to a higher reading as temperature increases
2. A change to a lower reading as temperature decreases
3. A change to a lower reading due to fuel dilution
4. There is no effect

6-12. What is the purpose of a visgage?

1. To determine dilution of lube oil
2. To determine operating temperature viscosity
3. To determine the viscosity of new lube oil
4. To determine the viscosity of fuel oil

6-13. Where is the sample oil placed in a visgage?

1. Primary tube
2. Secondary tube
3. Master tube
4. Trial tube

6-14. The reading on a visgage will be in SSU at what temperature?

1. 100°F
2. 122°F
3. 130°F
4. 210°F

6-15. The two balls in a visgage, moving at the same speed, indicate that the

1. sample oil is a higher viscosity
2. standard oil is not correct for the sample oil
3. sample oil is a lower viscosity
4. viscosity of the sample is the same as the standard

6-16. Lube oil in an engine should be changed whenever dilution has reached

1. 2%
2. 5%
3. 7%
4. 10%

6-17. If the viscosity of a new oil is 460 Saybolt Universal seconds at 100°F and the old oil is 320°F, what is the percentage of dilution?

1. 6%
2. 5%
3. 3%
4. 4%

6-18. In an operating engine, how often should you test the lube oil for fuel dilution?

1. Every 4 hours
2. Every 12 hours
3. Every 24 hours
4. Every 72 hours

6-19. To convert viscosities between 30 and 100 SSF to SSU, what number should you multiply by?

1. 5
2. 10
3. 15
4. 20

● In answering Items 6-20 through 6-22, select the correct answer from the following four alternatives:

1. The temperature at which flammable vapors will burn without application of a spark or flame
2. The temperature at which the heat of compression will ignite the vapor
3. The lowest temperature at which vapors will flash into flame when contacted with a flame
4. The lowest temperature at which vapors will continue to burn when ignited

6-20. What is the flashpoint of an oil?

6-21. What is the fire point of an oil?

6-22. What is the autogenous ignition point of an oil?

6-23. The ability of an oil to prevent the accumulation of carbon deposits in an engine is known as

1. durability
2. detergency
3. carbon content
4. carbon residue

6-24. Why is oxidation of lubricating oil detrimental to engine operation?

1. Rust will form on the cylinder walls
2. Sludge will accumulate in oil passages
3. Acid is produced which will deteriorate engine parts
4. Potassium Hydroxide is formed which will deteriorate engine parts

6-25. When using a centrifuge to test oil, which of the following tests are you making?

1. Neutralization number
2. Precipitation number
3. Carbon residue
4. Specific gravity

6-26. When testing the specific gravity of oil, which of the following conditions must you meet?

1. Stir the oil to remove air
2. Clean the instrument
3. Have the oil at room temperature
4. Each of the above

Learning Objective: Identify the points that must be considered when selecting oil for a specific purpose. Textbook pages 184 and 185.

6-27. To select the proper lubricant for a specific equipment, which of the following publications should you use?

1. NAVSHIPS' Technical Manual
2. NAVSUP Manual
3. NAVMAT Manual
4. Manufacturer's technical manual

6-28. The Navy symbol assigned to an additive type of heavy duty oil is of what series?

1. 1000
2. 2000
3. 7000
4. 9000

6-29. One purpose of an additive to mineral oil is to

1. inhibit oxidation
2. add nutrients
3. add carbon
4. inhibit precipitation

6-30. In a diesel engine, which of the following fluids will cause corrosion of alloy bearings?

1. Symbol 9110 lube oil
2. Symbol 9250 lube oil
3. Both 1 and 2 above
4. Partially burned fuel

6-31. When engine lube oil appears cloudy, what is the most likely cause?

1. Normal usage
2. Water contamination
3. Fuel dilution
4. Excessive temperatures

6-32. When the lubricating oil of a diesel engine turns dark in color after a few hours of use, what is indicated?

1. The oil should be purified
2. The lubricating quality of the oil has deteriorated
3. The oil is functioning normally
4. Normal operating temperature has been exceeded

Learning Objective: Point out principles of oil purification and separation. Textbook pages 186 through 193.

6-33. Which of the following are oil contaminants?

1. Intake air
2. Engine exhausts
3. Water
4. Each of the above

6-34. To increase the efficiency and decrease the time required for settling in a settling tank, what is done to the lube oil?

1. It is heated
2. It is agitated
3. It is circulated
4. It is cooled

6-35. To conduct the batch process of purification, oil is taken from the sump of a running engine, through the purifier and returned to the sump.

6-36. What principle is used to purify oil in a purifier?

1. Centrifugal force
2. Specific gravity
3. Differential pressure
4. Differential temperature

6-37. Fuel oil can be removed from lube oil by the lube oil purifier.

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6-38. When a purifier is used to remove water from fuel oil, it is called a

1. centrifuge
2. demulsifier
3. clarifier
4. separator

6-39. When a purifier is used to remove sediment from a lube oil, it is called a

1. centrifuge
2. demulsifier
3. clarifier
4. separator

6-40. In figure 9-7 of the textbook, dirty oil flows from the bottom of the regulating tube, through a tubular shaft into a

1. bowl shell
2. stack of disks
3. centrifugal tube
4. discharge ring

6-41. What happens during the purification process when a disk-type purifier is used?

1. Clean oil is discharged through the discharge ring; water mixed with sludge and dirt flows upward and is discharged from the neck of the top disk; most of the dirt and sludge collects on the vertical surface of the bowl shell
2. Clean oil is discharged through the discharge ring; water and most dirt and sludge is discharged through the drains; some dirt collects on the vertical surface of the bowl
3. Clean oil flows inward and upward through the disk and is discharged through the neck of the top disk; water mixed with dirt and sludge passes through the discharge ring; most of the dirt and sludge is collected on the vertical walls of the bowl shell
4. Clean oil flows inward and upward and is discharged through the top disk; water, dirt, and sludge, is discharged through the drains

6-42. What is the function of the three-wing device in the tubular-type centrifugal purifier?

1. To maintain a constant oil pressure
2. To cause the liquid to rotate at bowl speed
3. To restrain movement of the bottom of the bowl
4. To accelerate emulsification

6-43. Oil purifiers are designed to give maximum efficiency when the purifier is operating at

1. minimum speed
2. a speed determined by prevailing conditions
3. a speed between minimum and maximum, and at the rated capacity
4. maximum designed speed and rated capacity

6-44. When must the bowl of a purifier be primed with freshwater?

1. When operated as a separator
2. When operated as a clarifier
3. When operated as a centrifuge
4. When operated as a demulsifier

6-45. Most oils used by the Navy can be heated to what temperature without damaging the oils?

1. 195°F
2. 190°F
3. 185°F
4. 180°F

6-46. When military Symbol 9250 lube oil is to be purified, it should be heated to

1. 140°F
2. 160°F
3. 175°F
4. 180°F

6-47. The size of the discharge ring used in a purifier is determined by the

1. viscosity of the oil
2. moisture content of the oil
3. sediment content of the oil
4. specific gravity of the oil

6-48. What is the best method of determining the efficiency of a purifier?

1. Check oil for clarity
2. Oil analysis
3. Batch process
4. Amount of sediment found in the bowl

Learning Objective: Identify the type of oil pressure system used with modern internal-combustion engines. Textbook page 193.

6-49. Lubrication of modern internal-combustion engines is accomplished by what method?

1. Pressure
2. Splash
3. Drip
4. Wick

Learning Objective: Point out the functions of the various parts of a lubricating system. Textbook pages 193 through 200.

6-50. Which of the following lubricating system components is considered as internal to the engine?

1. Sump
2. Piping
3. Cooler
4. Filter

6-51. On a diesel engine, what controls the discharge rate of the positive-displacement, rotary-gear type lube oil pump?

1. A pressure regulating valve
2. A pressure relief valve
3. The engine speed
4. An orifice

6-52. In a diesel engine, what hazard(s) can be caused by overpriming the lube oil system?

1. Lube oil leaks at the seals
2. Fouling of injectors
3. Foaming of the oil
4. Overspeeding upon starting

6-53. When you are priming the lube oil system of a diesel engine, when should you stop?

1. When the lube oil gage registers a slight pressure
2. When the lube oil gage indicates 10 psig
3. When the temperature of the oil rises slightly
4. When the temperature of the oil rises 5°F

6-54. Which of the following statements describes filters?

1. They are wire mesh devices
2. They remove longer particles than strainers
3. There are two on every diesel lube oil system
4. They are replaceable

6-55. Which of the following statements describes strainers?

1. All strainers are of the duplex type
2. All approved lubricating oil strainers have a built-in pressure relief valve
3. All strainers contain an absorbent cartridge
4. All lube oil strainers can be cleaned during normal engine operation

6-56. In figure 9-10 of the textbook, where is the control valve handle located?

1. Upper left
2. Upper right
3. Lower left
4. Lower right

6-57. When the control valve is in the bypass position, where does the oil flow?

1. Through the filter to the engine
2. Through the head to the engine
3. Through the filter to the sump
4. Through the filter to the pump suction

6-58. When the relief valve on the edge-disk type oil strainer operates, where does the oil flow?

1. Down through the center and out
2. Down around the filter and out
3. Up around the filter and out
4. Up through the center and out

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6-59. In figure 9-11 of the textbook, what is the designation of the device you turn to clean the strainer?

1. Control handle
2. Wing handle
3. Relief valve
4. Cleaner blades

6-60. In Navy filters, which of the following absorbent materials is NOT approved for filters?

1. Cellulose
2. Cotton waste
3. Activated charcoal
4. Paper disks

6-61. How many types of filtering systems are approved for use with Navy diesel engines?

1. One
2. Two
3. Three
4. Four

6-62. In a shunt-type filtering system, what is the correct flow path of the oil?

1. Strainer, filter, cooler, engine
2. Filter, cooler, strainer, engine
3. Cooler, strainer, filter, engine
4. Engine, strainer, cooler, filter

6-63. In figure 9-17 of the textbook, which valve controls the bypass for the filter?

1. Control valve
2. Bypass valve
3. Relief valve
4. Pressure regulator valve

Learning Objective: Point out the purpose of scavenging pumps and lube oil vents on diesel engines. Textbook pages 200 through 204.

6-64. On a dry-sump type lube oil system, what is the purpose of the scavenging pump?

1. To supply oil to the main engine
2. To keep the oil pan nearly dry
3. To supply oil to the valve train
4. To circulate oil through the cooler

6-65. In a lubricating oil system, why are the internal cavities and related spaces vented through the engine intake air system?

1. To prevent combustible gas from accumulating in the crankcase
2. To prevent creating a fire hazard with fumes in the compartment
3. For the reasons in both 1 and 2 above
4. To reduce the possibility of sparks in the crankcase

6-66. Dilution of the lube oil with diesel fuel is the cause of all crankcase explosions.

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Assignment 7

Fuel and Fuel Systems

Textbook Assignment: Pages 205 through 239

Learning Objective: List requirements of fuel oil, explain how ignition quality is determined, and explain how turbulence is used in a diesel engine. Textbook pages 205 through 212.

7-1. What is the primary responsibility of an Engineman in dealing with fuels?

1. Testing fuels for Navy engines
2. Using and handling fuels correctly
3. Storing fuels properly aboard ship
4. Selecting appropriate fuels for Navy engines

7-2. Why is a richer fuel-air mixture required in starting a cold gasoline engine than in operating the engine after it is warm?

1. To lessen the chance of vapor lock
2. To improve the volatility of the gasoline in the fuel-air mixture
3. To ensure that a highly vaporized fuel mixture enters the cylinders
4. To compensate for gasoline condensing in the manifold

7-3. The octane value of a gasoline is the measure of the

1. potential energy of the gasoline
2. vaporization temperature of the gasoline
3. antiknock characteristics of the gasoline
4. starting qualities of the gasoline

7-4. Assume that Navy all-purpose gasoline is the only fuel available for an engine which is designed to operate with 80 to 87-octane gasoline but which is tuned for knock-free performance when using 87-octane gasoline. Which, if any, of the following actions should permit the engine to perform without knocking when using the Navy all-purpose fuel?

1. Advance the engine timing
2. Retard the engine timing
3. Change the air-fuel ratio
4. None of the above

7-5. Assume that 100-octane gasoline is the only fuel available for an engine which is tuned for knock-free performance when using 87-octane gasoline. Which, if any, of the following actions should improve the engine's performance when using the 100-octane gasoline?

1. Advance the ignition timing
2. Retard the ignition timing
3. Change the fuel-air ratio
4. None of the above

7-6. Leaded gasoline with which of the following octane numbers has the greatest toxic effect on the human body?

1. 80
2. 87
3. 94
4. 100

7-7. What three factors contribute to self-ignition of a diesel fuel within an engine?

1. Pressure, temperature, and air intake
2. Pressure, injection, and air intake
3. Pressure, time, and air intake
4. Pressure, temperature, and time

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7-8. In the operation of a diesel engine, which of the following factors determine(s) the amount of ignition delay?

1. The size of the fuel particles injected into the combustion space
2. The temperature and pressure within the combustion space
3. The turbulence within the combustion space
4. All of the above

7-9. Which of the following statements about detonation in a diesel engine is true?

1. Detonation is suppressed by increased ignition delay
2. Detonation occurs during the last stage of combustion
3. Detonation is caused by a simultaneous ignition of all of the fuel charge in a cylinder
4. Detonation is an instantaneous explosion of a small part of the fuel charge in a cylinder

7-10. The cetane number rates fuels according to

1. antiknock characteristics
2. ignition qualities
3. rates of vaporization
4. viscosity

7-11. Why is turbulence introduced into the cylinders of a diesel engine?

1. To regulate engine operating temperatures
2. To keep piston crowns from overheating
3. To help mix fuel and air better and faster
4. To sweep away unburned particles of fuel

7-12. Which of the following is NOT a means of creating turbulence in a diesel engine?

1. Increasing compression ratio
2. Shaping piston crowns
3. Positioning inlet ports
4. Shaping combustion chambers

7-13. Which design of combustion chamber does NOT use an auxiliary chamber to help mix injected fuel with combustion air?

1. Air cell
2. Open
3. Divided
4. Energy cell

When answering items 7-14 and 7-15, refer to the following principles upon which auxiliary combustion chambers work to create or to improve turbulent conditions in the cylinder spaces of diesel engines:

A. Part of the combustion air is trapped in an auxiliary chamber and is expanded by heat of compression, causing the air to jet out into the cylinder space at high velocity.

B. The rapid forcing of compression-heated air into the auxiliary chamber creates a turbulent action during the compression event due to the design of the chamber and size of the opening.

C. Fuel injected into an auxiliary chamber burns with insufficient oxygen causing unburned fuel to jet into the cylinder space at high velocity.

D. Piston upstroke forces more than half of the combustion fuel into the auxiliary chamber where it burns causing the resultant gases of combustion to swirl rapidly into the cylinder space at peak pressures.

7-14. The principle upon which the precombustion chamber works is

1. A
2. B
3. C
4. D

7-15. The principle upon which the turbulence chamber works is

1. A
2. B
3. C
4. D

7-16. In a diesel engine that uses an energy-cell auxiliary combustion chamber, during the injection event most of the combustion fuel remains in the

1. major air chamber
2. minor air chamber
3. main combustion chamber
4. connecting passages between the minor and major air chambers

7-17. Diesel engines in which divided combustion chambers create turbulence operate smoothly due to a gradual, rather than sudden rise in cylinder pressures during the combustion. The prolonged combustion that results in smoother engine operation is attributed to the

1. shape of the main combustion chambers
2. location of the energy cells relative to the pistons
3. location of the energy cells relative to the nozzles of the fuel injectors
4. restrictions in the passages that connect the major air chambers with the minor air chambers

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Learning Objective: Identify the various functions of a fuel injection system and explain why the function is required. Textbook pages 212-214.

Match the function of the fuel system in column A with its definition in column B.

A. Function	B. Definition
7-18. Atomization	1. Injection of fuel at a particular time
7-19. Timing	2. Accurate measurement of injected fuel
7-20. Metering	3. Breaking the fuel into a mist-like spray
	4. Range of adjustment of the amount delivered during injection

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7-21. In the fuel injection system of a diesel engine, which function provides uniform speed and uniform power?

1. Timing the fuel injection
2. Atomizing the fuel
3. Metering the fuel
4. Controlling the rate of fuel injection

7-22. The only effect of early injection of fuel in a cycle is low exhaust temperatures.

7-23. The effect of poor timing of a fuel injection system on the performance of a diesel engine is most similar to the effect of poor

1. metering of the fuel
2. control of the rate of fuel injection
3. atomization of the fuel
4. distribution of the fuel

7-24. In the fuel injection system, high pressure of injection ensures which of the following functions?

1. Atomization
2. Proper metering
3. Proper injection rate
4. Penetration

7-25. Penetration of the fuel into the combustion chamber is dependent on what type of energy?

1. Potential
2. Kinetic
3. Anemic
4. Robust

7-26. Uniform distribution of fuel in the combustion chamber is dependent on which of the following functions?

1. Injection pressure
2. Compression pressure
3. Size of injection hole
4. Each of the above

7-27. In a diesel engine, combustion is controlled by the governor which controls the amount of air admitted to the combustion chamber.

Learning Objective: Identify components of the external fuel system. Textbook pages 214-215.

7-28. In a centrifugal purifier, contaminants separate from fuel oil because they are

1. more viscous
2. heavier
3. more solid
4. lighter

7-29. When a cartridge-type filter becomes clogged, you must

1. clean it
2. vent it
3. replace it
4. drain it

Learning Objective: Give a brief description of the common-rail injection system. Textbook pages 215-219.

7-30. The nozzles of the modified common-rail injection system differ from those of the basic common-rail system in that the nozzles of the modified system

1. operate mechanically while in the basic system they operate hydraulically
2. operate hydraulically while in the basic system they are operated mechanically
3. meter the fuel while in the basic system fuel is metered by injectors
4. use wedges attached to a single shaft to compensate for engine load variations while in the basic system the outer sleeve of the injector compensates for engine load variations

7-31. In the modified common-rail fuel injection system, the fuel oil pressure is controlled by the position of the

1. accumulator bottle pressure valve
2. inner sleeve of the pump
3. relief valve adjusting screw
4. outer sleeve of the pump

7-32. In meeting the fuel demands of a variable-speed diesel engine, the modified common-rail injection system has an advantage over the basic common-rail systm; the modified system has a/an

1. hydraulically operated fuel-metering injector
2. automatic pressure control with load or speed changes
3. manually adjusted spring-loaded pressure regulator with load or speed changes
4. mechanically operated fuel-metering nozzle

Learning Objective: Give a brief description of the various pump-injection systems. Textbook pages 219-231.

7-33. The pump-injection system that combines a high-pressure pump and an injection nozzle into one unit is a unit injector.

7-34. The Bosch fuel injection pumps, APE and APF, differ in basic design according to the arrangement of the

1. control rack and the delivery valves
2. spray nozzles and the delivery valves
3. spray nozzles and the combustion chamber
4. cylinder plungers and the pump housing

7-35. Fuel injection in the Bosch system is completed when the injection pump's

1. inlet port is covered by the plunger
2. spill port is uncovered by the edge of the plunger helix
3. inlet and spill ports are both covered by the edge of the plunger helix
4. inlet and spill ports are both uncovered by the plunger

7-36. Which statement best describes the Bosch plunger injection pump marked "timed for port opening"?

1. Both upper and lower helices with a constant beginning and variable ending of injection
2. An upper helix with a variable beginning and constant ending of injection
3. A lower helix with a constant beginning and a variable ending of injection
4. Both upper and lower helices with variable beginning and ending of injection

7-37. The PSB pump requires less mounting space than an APE fuel pump because of its length.

7-38. The hydraulic head of the PSB fuel pump is a complete assembly which is fastened to the housing by means of a coupling.

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7-39. The Roosa-Master fuel system differs from that of the Bosch APE and PSB in regard to which of the following features?

1. Design of the governor
2. Design of the fuel filter
3. Method of measuring and pumping the fuel
4. All of the above

7-40. What component of the Roosa-Master fuel system provides accurate measurement of the fuel injected into each cylinder?

1. Rotor
2. Metering plunger
3. Injection nozzle
4. Four-vane positive-displacement pump

7-41. In the rotor of the Roosa-Master fuel injection system, the position of the drilled passages establishes the

1. amount of fuel injected
2. fuel injection pressure
3. timing relationship of nozzles
4. position of the injection pump plungers

7-42. In the PT system, what type of valve is the pressure regulator?

1. Relief
2. Bypass
3. Stop
4. Globe

7-43. In a Cummins PT system with a variable-speed governor, what limits the fuel delivery to the required amount for any given speed or load?

1. Governor
2. Gear pump
3. Throttle
4. Pressure regulator

7-44. In the Cummins PT injectors, the circulation of fuel is continuous EXCEPT for which of the following short periods?

1. During the injection period
2. Just before the injection period
3. Just after the injection period
4. During the metering period

7-45. The fuel pressure and the time the metering orifice remains open determine the amount of fuel injected into the combustion chamber of the Cummins PT fuel injection system.

7-46. The part of a unit injector that is mounted snugly in a copper tube within the cylinder head is cooled by

1. intake air
2. lubricating oil
3. water
4. fuel oil

7-47. In the high valve unit injector, the relation of the helices to the ports is changed by the

1. motion of the injector rocker arm
2. rotation of the plunger
3. velocity of the metered fuel as it passes through the helices
4. motion of the follower spring

7-48. A unit injector is classified according to the

1. size of its injector valve
2. design of its injector valve
3. number of orifices in its spray tip
4. method of securing it in the cylinder head

7-49. In the high valve unit injector, what causes the injector valve to leave its seat, thereby permitting fuel to be sprayed into the combustion chamber?

1. The force of gravity
2. The force stored in the injector valve spring
3. The force stored in the injector follower spring
4. Pressure that builds up in the injector

7-50. The beginning and ending of the injection period and the volume of fuel injected into the cylinder by a unit injector are changed by the

1. reciprocating motion of the plunger
2. volume of fuel passing through the injector outlet opening
3. rotary motion of the plunger
4. motion of the injector rocker arm

7-51. In which of the unit injectors is the check valve located in a recess on top of the valve seat?

1. High valve
2. Spherical valve
3. N-type needle valve
4. Needle valve

7-52. The intermixing of needle valve injectors of different types on the same engine should NOT be permitted as the injection characteristics differ from one type of injector to another.

Learning Objective: Identify different types of injection nozzles with their probable troubles and the necessary corrective actions. Textbook pages 231-237.

7-53. In the Bosch injector system the fuel oil travels from the injection pump to the nozzle holder body, passing through which of the following parts?

1. An orifice
2. A strainer
3. A circular passage
4. All of the above

7-54. In the Bosch hole-type nozzle injector the valve is raised from its seat by the spray tip by

1. a cam-operated push rod
2. a plunger and bushing assembly
3. a rack-controlled plunger
4. high-pressure oil in the oil cavity

7-55. Which type of nozzle is used in injectors if fuel atomization is more important than fuel penetration because of combustion chamber design?

1. Open
2. Pintle
3. Single hole
4. Multihole

7-56. In a fuel injection unit, low nozzle opening pressure results in

1. an increase in the amount of fuel injected
2. an increase in the rate of fuel atomization
3. a decrease in the amount of fuel injected
4. a delay in fuel injection per stroke

7-57. In testing an injector, you should avoid spraying fuel oil on your skin because the pressurized oil can penetrate the skin and cause blood poisoning.

7-58. If the opening pressure of a Bosch injector nozzle is too high because of improper spring action, the malfunction can be corrected by

1. adjusting the spring
2. replacing the nozzle unit
3. installing a new spring
4. replacing the nozzle valve

7-59. When a pressure in excess of the pop pressure can be built up in a unit injector, the condition is usually caused by

1. dirty sealing surfaces
2. weak valve springs
3. broken pressure springs
4. improper assembly of parts

7-60. A broken pintle in a fuel injection system usually causes

1. corrosion of the spray nozzle
2. clogging of orifices
3. distortion of the spray pattern
4. erosion of valves

7-61. The recommended corrective action for eroded nozzle orifices is to

1. clean the nozzle openings with a wire
2. immerse the nozzle in clean diesel oil
3. replace the nozzle
4. sandblast the nozzle

7-62. Which of the following injection system defects will NOT cause nozzle dribbling?

1. Damaged valve body seat
2. Broken pressure adjusting spring
3. Dirty nozzle
4. Broken injector tip

Learning Objective: Give a brief description of purging the fuel injection system. Textbook pages 237-238.

7-63. The pressure of air in the fuel system of a diesel engine could cause

1. misfiring
2. stalling
3. knocking
4. misfiring, stalling, or knocking

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7-64. Which of the following appearances of fuel indicates air in the system?

1. Clear
2. Cloudy
3. Dark
4. Light

7-65. Air will enter the fuel system in most cases in the suction side of the injection system. Therefore, you must inspect the suction piping and fittings when an air leak is suspected.

7-66. Assume that a small high-speed diesel engine fails to start due to the presence of air in the high-pressure fuel lines. Priming should be attempted first at the

1. overflow connection on the pump housing
2. injection valves
3. priming pump
4. transfer pump

Learning Objective: Relate the Pollution Control Act to the duties of an Engineman. Textbook pages 238 through 239.

7-67. Which, if any, of the following types of pollution was reduced by changing from Navy Special Fuel Oil to distillate fuel?

1. Air
2. Water
3. Soil
4. None of the above

7-68. What is the minimum distance from shore that a ship may pump oily bilges?

1. 12 miles
2. 50 miles
3. 100 miles
4. 150 miles

7-69. Ships are NOT normally allowed to transfer oil between tanks in restricted waters.

7-70. Ballast can be pumped overboard after it has been allowed to settle.

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Assignment 8

Propulsion Control Systems: Diesel Engine Operating Procedures

Textbook Assignment: Pages 240 through 259

Learning Objective: Identify the types of engine controls by their functions and describe mechanical and hydraulic governor action. Textbook pages 240 through 243.

8-1. The speed and power output of a diesel engine are increased by increasing the charge of

1. air entering the cylinders
2. fuel entering the cylinders
3. air and fuel entering the cylinders
4. fuel and by decreasing the charge of air entering the cylinders

8-2. A governor that controls the flow of fuel oil to the injectors at all engine speeds between idling and maximum is classified as a

1. constant-speed governor
2. load-limiting governor
3. variable-speed governor
4. speed-limiting governor

8-3. A control device that limits engine load at various speeds is called a

1. speed-limiting governor
2. variable-speed governor
3. constant-speed governor
4. load-limiting governor

8-4. What is meant by isochronous governing of the speed of a diesel engine?

1. Speed varies with load changes
2. Speed remains constant under all load conditions
3. Speed is maximum under overload conditions
4. Idling speed is maintained under minimum load conditions

In the following items, match the term in column A with the best definition in column B.

A. Term	B. Definition
8-5. Hunting	1. Speed of action of governor
8-6. Stability	2. Ability to maintain speed without fluctuating
8-7. Sensitivity	3. Continuous fluctuating speed
	4. Amount of speed change required before the governor will take corrective action

8-8. In the centrifugal governor of a diesel engine, the rotational speed of the flyballs is determined directly by the

1. throttle setting
2. governor spring pressure
3. engine speed
4. adjusting device

8-9. Assume that a diesel engine is operating under variable loads and that no manual adjustments are made by the operator. In the governor of the engine, centrifugal force of the flyballs becomes greater than the pressure exerted by the coil spring as a consequence of which of the following events?

1. A decrease in the amount of fuel delivered to the engine
2. An increase in load
3. Either 1 or 2 above
4. A decrease in load

8-10. The force exerted by the coil spring on the flyballs in a governor is equal to the centrifugal force of the flyballs when the diesel engine is operating at

1. constant speed with a variable load
2. variable speeds with a variable load
3. constant speed with a constant load
4. variable speeds with a constant load

8-11. In figure 11-1 of the textbook, if the flyballs move out, what, if anything, will happen to the rate of fuel flow?

1. Increase
2. Decrease
3. Increase then decrease
4. Nothing

8-12. In figure 11-2 of the textbook, hydraulic oil is being ported to the under or lower side of the power piston. What, if anything, is happening at the fuel valve?

1. It is opening
2. It is closing
3. It will close then open
4. Nothing

8-13. In figure 11-3 of the textbook, what forces the power piston down?

1. Hydraulic pressure
2. The speed adjusting spring
3. A compensating spring
4. The power spring

8-14. Why are mechanical governors rather than hydraulic governors used on small diesel engines?

1. High fuel injection pressure is not necessary
2. Large amounts of fuel are not handled
3. Faster operation is required
4. Extremely accurate regulation is not necessary

Learning Objective: Describe overspeed devices, while giving the purpose of the safety devices. Textbook pages 243 and 244.

8-15. Operating a diesel engine at excessive speeds can cause its rotating parts to break apart.

8-16. Assume that you are required to stop a diesel engine that is overspeeding, and you are unfamiliar with its design and operation. How should you stop the engine?

1. Use the throttle to cut off the fuel supply
2. Block the fuel line by closing the valve on the line
3. Block its flow of intake air
4. Relieve the pressure in the fuel line by opening a valve

8-17. An overspeed trip will stop a diesel engine that is equipped with a speed governor when the regular speed governor fails to

1. limit the load on the engine
2. keep engine speed below the maximum designed limit
3. keep engine speed above the minimum designed limit
4. keep the engine from hunting excessively under normal loads

8-18. The shutoff control in a mechanical or hydraulic overspeed governor is operated by a power spring.

Learning Objective: Describe the various types of propulsion controls, pneumatic, hydraulic and electrical. Textbook pages 244 and 245.

8-19. In a controllable pitch propeller, which of the following requirements is met by either pneumatic or hydraulic signal?

1. Control of engine load
2. Control of shaft speed
3. Control of shaft direction
4. Control of propeller pitch

8-20. The EOS can control the steering gear.

8-21. On ships with CRP propellers, the pilothouse console can control starting and stopping of main engines.

Learning Objective: Identify the general procedures for starting diesels after prolonged periods of idleness, overhaul, and routine securing. Textbook pages 246 through 248.

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8-22. The Engineering Operation Sequencing Standards (EOSS) is written for the Department Head's guidance only.

8-23. What is the first step in the general starting procedure for a diesel engine?

1. Crank the engine
2. Perform preoperational checks
3. Align the supporting systems
4. Vent the freshwater cooling system

Match the starting procedure for a diesel engine in column A with the component or system in column B.

	A. Procedure	B. Component/System
8-24.	Align valves	1. Expansion tank
8-25.	Check freshwater level	2. Sump
		3. Seawater cooling
8-26.	Check oil level	4. Heat exchanger

8-27. After a large diesel engine has been idle, how is the oil film restored to the cylinder walls?

1. By pressurizing the lube oil system and jacking the engine
2. By the lube oil injection system
3. By hand wiping
4. Through the inspection port

8-28. To reduce load during jacking operations, what should you do?

1. Open the fuel line
2. Open the expansion tank
3. Open cylinder test valves
4. Open the sea valve

8-29. When is the check for malfunctioning alarms performed?

1. Before lining up the fuel system
2. After starting the engine
3. When lining up the freshwater cooling system
4. After lining up the fuel system

8-30. In re-starting a warm engine, which of the following reactions may be expected?

1. Excessive fuel use
2. Longer starting period
3. High coolant temperatures
4. High oil pressure

Item 8-31 and 8-32 are concerned with the steps you are to follow in preparing to start a diesel engine that has just been overhauled.

8-31. In starting a diesel engine after a long idle period, each of the following procedures must be performed. What is the correct sequence?

A. Check operating condition of governor
B. Fill the freshwater system
C. Check tagged valves
D. Make a visual check to see whether oil is present at all bearings
E. Check all pipe connections
F. Inspect air receiver

1. A, C, D, E, B, F
2. C, A, B, E, D, F
3. C, E, B, D, F, A
4. C, E, B, D, A, F

8-32. Disconnected air-starting lines are blown out and reconnected so that the specified pressure will build up before you

1. check timing of fuel injectors
2. check valve assemblies for freedom of movement

[illegible]. clean fuel oil strainers

4. open scavenging-air header manifold drains

Learning Objective: List the procedures to follow during routine operation of a diesel engine. Textbook pages 248-251.

8-33. Which of the following is a long-range benefit to be obtained from keeping logs?

1. The detection of high temperature
2. The detection of low water pressure
3. The detection of gradually degraded operation
4. The detection of back pressure

8-34. What is the minimum load at which a diesel engine should be allowed to operate for any length of time?

1. One-fourth normal load
2. One-third normal load
3. One-half normal load
4. Two-thirds normal

8-35. In a diesel engine, what potentially damaging condition is indicated by excessive firing pressures?

1. Excessive rate of water flow
2. Overload
3. Inadequate lubrication in engine cylinders
4. Corrosion of the fuel intake valve

8-36. How can you clean the metal-edge type strainer without interrupting the flow of oil?

1. Insert new cleaner blades
2. Reduce the oil input by one-half
3. Replace the sump of the strainer
4. Turn the external handle

8-37. Which of the following operating conditions causes deposits of salt in the coolers and piping of engines?

1. Low temperatures in the saltwater cooling system
2. Excessive temperatures in the saltwater cooling system
3. Excessive temperatures of the lubricating oil
4. Low temperatures of the lubricating oil

8-38. The operating efficiency of a saltwater cooled engine will decrease unless the coolant discharge temperature is between

1. 140° and 180°F
2. 140° and 170°F
3. 100° and 130°F
4. 100° and 180°F

8-39. Which of the following operating conditions is a cause of fractured crankshafts?

1. Excessive speed-up of load to an engine
2. Excessive vibration in the engine
3. Excessive rate of water flow
4. Excessive rate of oil intake

8-40. How can you effect a gradual reduction of diesel engine temperature?

1. Allow the engine to idle for a while before stopping it
2. Gradually increase the amount of freshwater in the cooling system
3. Gradually reduce the rate of oil intake
4. Reduce size of the bypass-valve opening

8-41. When should you open the drain cocks on the exhaust lines of a diesel engine?

1. Before the engine is started
2. While the engine is idling
3. When the engine is operating with a capacity load
4. After the engine has stopped

Learning Objective: Identify operating precautions for diesel engines. Textbook page 251.

8-42. In the operation of diesel engines, which of the following actions is contrary to accepted safety practices?

1. Centrifuging oil thoroughly before use
2. Ensuring that relief valves are not left in locked position
3. Stopping engine if operating temperature is too high
4. Pumping fuel into cylinders while testing valves

Learning Objective: Give a brief description of emergency diesel generators and how they operate. Textbook pages 252-253.

8-43. The emergency generators in most naval ships are powered by

1. gasoline engines
2. diesel engines
3. steam turbine engines
4. gas turbine engines

8-44. In an emergency generator system rated at 230 volts, at what voltage will the starting mechanism be triggered?

1. 250 volts
2. 203 volts
3. 184 volts
4. 152 volts

8-45. A diesel emergency generator with an air starting system will start automatically under which of the following conditions?

1. Current flowing in solenoid curcuit; valve handwheel in open position
2. Current flowing in solenoid circuit; valve handwheel in closed position
3. Current not flowing in solenoid circuit; valve handwheel in open position
4. Current not flowing in solenoid circuit; valve handwheel in closed positon

8-46. Assume that an air-started diesel engine is located in a compartment that has no direct supply of outside air for the engine intake manifold. What action, if any, must you take before starting the engine to ensure a continuous supply of air for you and the engine?

1. Open the starting air tank valve to admit air to the compartment
2. Open the fittings of the ventilation system serving the compartment
3. Charge the compartment with air from the high-pressure air system
4. No action is required before starting the engine

Learning Objective: Identify factors that affect casualty control. Textbook pages 253 through 255.

8-47. Which of the following factors of casualty control is NOT controlled by the ship's engineering department?

1. Design
2. Plant maintenance
3. Personnel training
4. Inspection

8-48. In casualty control, how many methods of communication are available before messengers are required?

1. Five
2. Two
3. Three
4. Four

8-49. Which of the following symptoms indicate an engineering malfunction?

1. Usual noises
2. Normal temperature
3. Normal pressures
4. Abnormal operating speeds

8-50. To determine the presence of instrument error, what should you do if a gage gives a low reading?

1. Replace the gage
2. Install a duplicate gage
3. Ignore the gage
4. Repair the gage

8-51. If a fuel oil suction pump fails, what should you do after replacing the pump?

1. Inspect all similar pumps
2. Install a spare pump
3. Check the suction of the failed pump
4. Check the strainer of the failed pump

8-52. How is saltwater detected in an oil sample?

1. Standard methyl test
2. Standard methyl flouride test
3. Standard fluoride test
4. Standard chloride test

8-53. Casualty training should be preceded by a dry run or two.

Learning Objective: Identify the phases of casualty control. Textbook pages 255 and 256.

8-54. Who has the ultimate responsibility for continuing to operate under a casualty condition?

1. Engineer officer of watch
2. Chief engineer
3. Officer of the deck
4. Commanding officer

8-55. How soon after an engineering casualty is it safe to cross connect two systems?

1. As soon as the damaged unit is stopped
2. As soon as it has been determined that the system under casualty will not adversely affect the cross connected system
3. As soon as it has been determined that the second system is operational
4. Each of the above is correct

Identify the casualties listed in column A with its proper phase number in column B.

	A. Casualty	B. Phase of Casualty Control
8-56.	Emergency restoration	1. 1st
8-57.	Limitation of casualty	2. 2nd
		3. 3rd
8-58.	Complete repair	4. 5th

8-59. The fuel oil service pumps are normally connected so that the after pump services the forward engine.

8-60. In the geared diesel propulsion plants, which of the following auxiliary systems can usually be cross connected?

1. Cooling water
2. Lube oil
3. Fuel oil
4. Each of the above is correct

8-61. When an engineering casualty occurs to a diesel engine which drives a reduction gear, the main shaft is locked by which of the following methods?

1. Brake
2. Jacking gear
3. Varying
4. All of the above

Learning Objective: Identify procedures for engineroom casualties. Textbook pages 257 and 258.

8-62. When there is a casualty in the engineroom, the Engineer Officer of the Watch shall notify the Officer of the Deck. What information must he supply the bridge?

1. The nature of the casualty
2. The ability of the engineroom to answer bells
3. The maximum speed available
4. All of the above

8-63. In an emergency, a diesel engine can be operated for a limited time with salt-water in the cooling system without appreciable damage.

8-64. In an emergency, a diesel engine can be stopped by discharging a CO_2 extinguisher into the fuel supply.

Assignment 9

Troubleshooting and Transmission of Engine Power

Textbook Assignment: Pages 260 through 299

Learning Objective: Identify the duties and requirements of a troubleshooter. Textbook pages 260-261.

9-1. Which of the following senses is/are used by the diesel engine troubleshooter?

1. Tasting
2. Seeing
3. Hearing
4. Both 2 and 3 are correct

9-2. Frequently, instruments give the first symptom of trouble. To identify a variation from normal the troubleshooter must

1. take the reading at regular intervals
2. record the changes in readings
3. know the specified operating instructions
4. report the reading to EOOW

9-3. Which of the following actions will be the greatest aid in detecting minor leakage?

1. Standing watch
2. Conducting material inspection
3. Conducting administrative inspection
4. Conducting routine cleaning

9-4. Basically, troubleshooting a diesel engine requires knowledge of the various systems within the engine. However, this knowledge does NOT need to include construction and function of the parts.

Learning Objective: Identify the various symptoms with the faulty system when a diesel engine fails to start. Textbook pages 261 through 269.

9-5. When an engine can be cranked but fails to start, which of the following troubles may be present?

1. Improperly engaged jacking gear
2. Insufficient compression
3. Depleted air supply
4. Faulty air distributor

9-6. When a diesel engine can neither be cranked nor barred over, which of the following troubles is most probably indicated?

1. A depleted air supply
2. An open cylinder relief valve
3. An improperly engaged turning gear
4. An out-of-time air starting motor

● To answer questions 9-7 and 9-8, use the following condition: An engine can NOT be cranked, but it can be barred over.

9-7. Of the following, which is the most probable fault?

1. Improper throttle setting
2. Tripped overspeed device
3. Engaged jacking gear interlock
4. Seized piston

9-8. Of the following systems, which is the most probable source of the trouble?

1. Air starting system
2. Fuel system
3. Ignition system
4. Lubrication system

9-9. Which of the following troubles may be detected through the scavenging air port?

1. Stuck piston rings
2. Seized bearing
3. Faulty air starting distributor
4. Scored bearing

9-10. What causes most of the troubles in a direct mechanical lift air timing system?

1. Improper adjustments
2. Insufficient lubrication
3. Dirt and gum deposits
4. Inadequate cooling

9-11. On a rotary distributor air timing mechanism, what should you use to check the contact between the rotor and the body?

1. Feeler gage
2. Prussian blue
3. Clearance light
4. Micrometer

9-12. Which of the following practices tends to reduce or eliminate the formation of gummy deposits that cause upper and lower pistons of pressure-activated air-starting valves to stick in the cylinders?

1. Increasing the tension of the valve return springs
2. Draining the storage tanks and water traps of the air-starting system
3. Jacking the engine over manually before starting to free any valves that may be stuck
4. Decreasing the tension of the valve return springs

9-13. What should you do if the upper piston of an air-actuated starting valve sticks because of gummy deposits?

1. Force alcohol around the pistons
2. Blow clean hot air around the pistons
3. Put light oil around the valve and work the valve up and down
4. Remove the piston and buff it with jewelers' rouge

9-14. In general, what should you do if a pressure-actuated air starting valve is not functioning properly because of a weak return spring?

1. Place another washer on top of the valve stem
2. Replace the castellated nut with a heavier one
3. Re-stress the valve return spring
4. Install a new valve return spring

9-15. If mechanical lift air-starting valves fail to close because of tight packing nuts, the diesel engine may be hard to start.

9-16. What is the main source of fuel pump and injection system troubles?

1. Contaminated fuel
2. Improper adjustments
3. Coated fuel lines
4. Excessive vibration

9-17. Metal fatigue in the nipples of a fuel system is usually caused by

1. leakage
2. high injection pressures
3. vibration
4. erosion

9-18. What are the main causes of leakage in fuel tanks?

1. Corrosion and excessive fuel line pressure
2. Metal fatigue and improper welds
3. Vibration and metal fatigue
4. Clogged fuel lines and corrosion

9-19. Which of the following problems is likely to cause failure of a diesel engine mechanical governor?

1. Faulty oil seals
2. Bound control linkage
3. Defective cold starting device
4. Low oil level

9-20. You can cause the overspeed safety device of an engine to become inoperative by

1. trying to start the engine with low starting air pressure
2. tripping the device accidentally while trying to start the engine
3. shutting off the fuel supply after starting the engine
4. shutting of the air supply after starting the engine

9-21. Most diesel engines are equipped with a special means of cutting off their air or fuel supply in an emergency. In which of the following situations would the special means be used?

1. Engine cannot be cranked or barred over
2. Parts of the exhaust system are obstructed
3. Fuel oil injection system is not properly timed
4. Overspeed safety device does not operate when speed becomes excessive

9-22. Slow cranking of a cold diesel engine may be caused by use of which of the following substances?

1. Detergent lube oil
2. High viscosity lube oil
3. Either of the above
4. Centrifuged lube oil

Learning Objective: Identify and troubleshoot causes of irregular diesel engine operation. Textbook pages 269 through 280.

9-23. What diesel engine system is likely to be at fault if a cylinder misfires regularly?

1. Lubrication
2. Fuel
3. Exhaust
4. Ignition

9-24. A cylinder compression leak is indicated when the pressure in a particular cylinder of an engine

1. is much higher than that in the other cylinders
2. is much lower than that in the other cylinders
3. fluctuates from normal to much below specified pressure
4. fluctuates from normal to much above specified pressure

9-25. After being cleaned, most engine air cleaners of the oil-bath type should be refilled to what level?

1. The full mark
2. Slightly above the full mark
3. The halfway mark
4. Slightly less than the halfway mark

9-26. If the water in the cooling system of a diesel emergency generator overheats because the thermostat fails to function, what action should you take?

1. Clean the bellows of the element
2. Adjust the tension of the regulator spring
3. Clean the freshwater cooler
4. Replace the thermostat

9-27. In the Fulton-Sylphon automatic temperature regulator, what happens if you decrease the spring tension?

1. The velocity of the cooling water decreases
2. The temperature range of the regulator increases
3. The velocity of the cooling water increases
4. The temperature range of the regulator decreases

9-28. Which of the following defects will cause back pressure?

1. Obstruction in combustion space
2. Thermostat failure
3. Restricted exhaust
4. Restricted oil filter

9-29. Which of the following can damage the turbine blading of a centrifugal blower?

1. Foreign objects
2. A bearing failure
3. Overspeeding
4. Any of the above

9-30. How can you determine whether blower rotor gears are worn excessively?

1. Measure the clearance between the leading and the trailing edges of the rotor lobes
2. Measure the backlash of the gear set
3. Measure the clearances between the rotor lobes and the casing
4. Check the timing of the rotors

9-31. If an engine shows power loss, frequent stalling, and starting failures, one of the contributing troubles is likely to be

1. low cooling water temperature
2. faulty operation of the governor
3. improperly engaged jacking gear
4. faulty air-starting distributor

9-32. If you are checking an engine for a stuck fuel control rack, what should you do immediately after disconnecting the linkage to the governor?

1. Visually inspect the rack
2. Try to move the rack by hand
3. Test the return springs
4. Remove the rack

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9-33. A properly operating engine governor may fail to have any control over a sudden increase in speed under which of the following conditions?

1. Injector leakage during operation
2. Sudden drawing of lube oil into the cylinders from the air box
3. Manifold explosion caused by excessive accumulation of oil
4. Inoperative cylinder relief valves

9-34. Before assembling new oil seals, what should you do to them?

1. Wash them in a detergent
2. Spray them with paraffin
3. Run them through a blower
4. Soak them in clean, light lube oil

9-35. What must be done to a safety valve if it is removed from an engine cylinder?

1. Spring tension must be reset
2. Shear pin must be replaced
3. Valve must be machined and lapped in
4. Valve must be replaced with a new valve

9-36. If the exhaust ports of an engine become clogged during operation, which of the following is a possible result?

1. High exhaust temperatures
2. Overheating of the engine
3. Popping of the cylinder safety valves
4. Any of the above

9-37. While cleaning the cylinder ports of an engine, you can prevent carbon from entering the cylinder by jacking the engine until the piston covers the ports.

Learning Objective: Identify symptoms of engine trouble with their associated corrective actions. Textbook pages 280 through 282.

9-38. What kind of noise will most likely be coming from an engine operating with a broken engine part?

1. Rattling
2. Clicking
3. Pounding
4. Knocking (detonation)

9-39. The color of the exhaust smoke of an engine can be used as an aid in which of the following circumstances?

1. Troubleshooting
2. Determining engine performance
3. Determining serious engine troubles
4. All of the above

Learning Objective: Identify possible dangers and troubles associated with gasoline engines and describe the necessary corrective action. Textbook pages 282 through 286.

9-40. An explosion may occur if a cigarette is lit near a storage battery because of the presence of

1. hydrogen gas
2. carbon monoxide
3. sulphuric acid
4. gasoline fumes

9-41. Failure of a gasoline engine starting motor to run may be caused by corroded, loose, or burned battery terminals.

9-42. When the starting motor of a gasoline engine turns but fails to crank the engine, the trouble is usually found in the

1. drive assembly
2. engine timing
3. fuel system
4. ignition system

9-43. Overpriming a gasoline engine can result in

1. an overheated engine
2. an inoperative fuel pressure gage
3. stuck piston rings
4. corroded piston crowns

9-44. Assume that you are checking for trouble in a fuel system that has a wobble pump. If the pump feels or sounds dry, where is the trouble probably located?

1. In the carburetor
2. In the line to the fuel pump
3. In the fuel pump
4. Between the fuel pump and the supply tanks

9-45. If a gasoline engine with a battery type ignition system fails to stop, what is the likely cause?

1. Contact switch points are open
2. Ground connection is open
3. Contact switch points are closed
4. Battery terminals are burned

Learning Objective: Describe briefly the electrical system of small boats. Textbook pages 286 and 287.

9-46. A small boat's electrical system is usually classed as what type of wiring system?

1. Single-wire, grounded
2. Single-wire, ungrounded
3. Two-wire, grounded
4. Two-wire, ungrounded

9-47. Which of the following circuits is/are fused?

1. Starting
2. Battery charging
3. Radio and signal light
4. Voltage regulator

Learning Objective: Explain factors concerned in the transmission of engine power and solve gear ratio problems. Textbook pages 288 and 289.

9-48. Torque is the force that drives a piston in a straight line.

9-49. Which of the following functions does a gear or combination of gears serve?

1. To increase or decrease torque
2. To increase or decrease a twisting force to the driven unit
3. To increase or decrease the rotational movement of an object
4. Each of the above is correct

9-50. For what purpose would you increase or decrease the speed of a driven unit?

1. To ensure that both the driving and the driven units operate at their most efficient speeds
2. To keep the driving unit from overspeeding
3. To keep the driven unit from overspeeding
4. To ensure that both the driving unit and the driven units operate at safe speeds

9-51. The crankshaft of an engine is fitted with a driving gear that has 20 teeth and a driven gear with 40 teeth. If the driving gear is turning at 6,000 rpm, what is the speed of the driven gear?

1. 3,000 rpm
2. 4,000 rpm
3. 6,000 rpm
4. 8,000 rpm

9-52. If the driving gear has 40 teeth and the driven gear has 10 teeth, what is the speed of the driven gear when the driving gear turns at 700 rpm?

1. 70 rpm
2. 17.5 rpm
3. 2100 rpm
4. 2800 rpm

9-53. Gear trains which change speed always change torque; when speed increases, the torque decreases proportionally.

Learning Objective: List the different types of drive mechanisms and their purposes. Textbook pages 289 through 293.

9-54. Which of the following drive mechanisms is usually used in power plants that always operate at a constant speed and torque?

1. Indirect drive
2. Reduction gear drive
3. Electric drive
4. Direct drive

9-55. Backing down Navy boats is usually done by reversing the

1. pitch of the propeller
2. direction of rotation of the propeller shaft
3. position of the engine relative to the propeller shaft
4. rotation of the engine crankshaft

9-56. One function of the clutch in the drive mechanism of a power boat is to

1. permit changes in gear ratio
2. reverse the pitch of the propeller
3. disconnect the engine from the propeller shaft
4. reverse the direction of engine rotation

9-57. In figure 14-2 of the textbook, where is the reduction gear unit located?

1. In the clutch housing
2. To the rear of the drum
3. In the reverse gear housing
4. Under the brake bank

9-58. In the CODOG system shown in figure 14-3 of the textbook, where are the gas turbine clutches located?

1. On the propeller shafts
2. At the first reduction gear
3. At the second reduction gear
4. At the gas turbine

9-59. In a diesel-electric driven ship, to what are the diesel engines connected?

1. To the propeller
2. To the motor
3. To the generator
4. Any of the above may be correct

9-60. The diesel-electric plant can be controlled electrically. With this type of control system, which of the following advantages is obtained?

1. Full power reverse
2. Higher speeds forward
3. Both 1 and 2 are correct
4. Remote control from the bridge

9-61. In a diesel-electric drive installation, propeller rotation is reversed by reversing the flow of current through the driving motor.

9-62. Which of the following materials is used to make the flexible element that joins the solid halves of a flexible coupling?

1. Neoprene
2. Rubber
3. Steel springs
4. Any of the above

Learning Objective: Identify clutches and reverse and reduction gears with their purposes and types. List some of the troubles that are encountered with clutches. Textbook pages 294 through 299.

9-63. By what means are low propeller-shaft speeds obtained in boats powered by high-speed engines?

1. Clutches
2. Reverse gears
3. Reduction gears
4. Pitch-changing devices

9-64. What type of clutch is used in the clutch assembly of the Gray Marine transmission mechanism?

1. Dry-type, single-disk
2. Dry-type, twin-disk
3. Wet-type, single-disk
4. Wet-type, twin-disk

9-65. The operator controls the direction that the Gray Marine engine turns the propeller shaft by shifting the position of the

1. reverse plate
2. forward plate
3. floating plate
4. neutral plate

9-66. The front plate of the Gray Marine engine transmission mechanism is bolted to and rotates with the

1. forward disk
2. engine flywheel
3. forward sleeve shaft
4. reverse disk

9-67. A reverse operation of the shaft and propeller driven by the Gray Marine engine is accomplished by

1. reversing the crankshaft rotation
2. engaging the reverse disk and gear train
3. reversing the forward disk rotation
4. reversing the back plate

9-68. How is the reversing gear unit lubricated?

1. By oil pressure from the engine
2. By its own splash system
3. By grease fittings
4. By both 2 and 3 above

9-69. Which of the following faults will cause clutch slippage?

1. Insufficient pressure
2. Overload
3. Fouling
4. Each of the above

9-70. In the twin-disk clutch, if a spring tester is not available, how can you check the springs?

1. Check the diameter
2. Check the free lengths
3. Use scales
4. Check the compressed length

9-71. Which of the following actions was probably the source of slippage, due to fouling, of a recently overhauled dry-type clutch?

1. Engaging the clutch while the engine was racing
2. Handling the clutch facings with greasy hands
3. Overloading the engine
4. Nicking or scoring the clutch facings

9-72. Assume that a dry-type clutch develops excessive clutch chatter. When you open up the unit, you find that the linings have been fouled by grease. How do you correct the trouble?

1. Wipe the grease off the linings with a clean dry rag
2. Soak the linings in kerosene to dissolve the grease
3. Clean the grease off the linings with hot soapy water
4. Replace the clutch linings

9-73. What type of pressure is used to engage the airflex clutch?

1. Spring
2. Centrifugal
3. Air
4. Hydraulic

9-74. In the airflex clutch, engaging the reverse clutch causes the forward pinion to

1. continue to rotate in the same direction
2. rotate in the opposite direction
3. stop rotating
4. stop, then begin again to rotate in the same direction

Assignment 10

Transmission of Engine Power (Continued) and Pumps and Valves

Textbook Assignment: Pages 299 through 331

Learning Objectives: Identify clutches and reverse and reduction gears with their purposes and types. List some of the troubles that are encountered with clutches. Textbook pages 299 through 307.

10-1. Through which of the following devices is the airflex clutch controlled?

1. Air box
2. Air check valve
3. Air control housing
4. Cone clutch

10-2. How much time is required to deflate a clutch in the airflex clutch assembly?

1. 2 sec
2. 7 sec
3. 12 sec
4. 17 sec

10-3. The emptying holes in the rotor housing of a hydraulic coupling are opened and closed by the

1. drive shaft
2. ring valve mechanism
3. impeller
4. oil seal

10-4. The scoop tubes in the scocp control coupling found in Navy hydraulic engines are operated from the control stand by means of

1. motors
2. linkages
3. gravity
4. pumps

10-5. The secondary rotor of a hydraulic coupling always rotates at a speed that is

1. greater than that of the primary rotor
2. equal to the speed of the primary rotor
3. less than that of the primary rotor
4. equal to or less than the speed of the primary rotor

10-6. What generally causes a hydraulic coupling to dump when under a load?

1. Excessive pressure
2. Low temperatures
3. Fouled oil system
4. Fluid friction

10-7. Assume that an induction coupling is being used in a propulsion system wherein a shaft is driven by either a forward or a reverse running engine. Advantages to be gained by the use of the induction coupling include the capability to do which of the following?

1. Disconnect instantaneously either engine from the shaft
2. Select either engine to drive the shaft
3. Limit the maximum torque whenever either engine is overloaded
4. Do all of the above

10-8. What advantage is gained by an installation that uses both a dog clutch and a friction clutch?

1. The friction surfaces can be constructed of the same material
2. Speed control as fine as that available from an electromagnetic clutch can be obtained
3. Torsional vibration is completely eliminated
4. The wear on the friction clutch is very small

Learning Objective: Explain the purpose of thrust bearings. Describe how shaft bearings are installed. Textbook pages 307-309.

10-9. Where is the bearing of the Kingsbury thrust bearing installed?

1. In the reduction gear
2. In the clutch
3. Fixed to the ship's frame
4. Fixed to the propeller shaft

10-10. What type of pressure is taken by the Kingsbury thrust?

1. Radial
2. Axial
3. Centrifugal
4. Pneumatic

10-11. In the Kingsbury thrust bearing, the collar is part of the

1. bearing
2. propeller
3. housing
4. clutch

10-12. How are spring bearings lubricated?

1. Oil pressure
2. Splash
3. Ring oiled
4. Grease fittings

10-13. The strut bearing is a shaft bearing that is located outside of the skin of the ship. By what is it lubricated?

1. Oil splash
2. Water
3. Oil pressure
4. Grease fittings

Learning Objective: List the advantages of and describe the operation of a controllable pitch propeller. Textbook pages 309 and 310.

10-14. Reverse gears are required with controllable-pitch propellers because pitch changes apply to forward maneuvering only.

10-15. Which of the following is an advantage of the controllable pitch propeller?

1. It eliminates the need for a reverse gear
2. It can be remotely controlled
3. It can be used with high horsepower gas turbines
4. Each of the above is correct

Learning Objective: List the different types of pumps with their uses and operating procedures. Identify their basic parts. Textbook pages 311 through 326.

10-16. The positive-displacement rotary pump is capable of which of the following actions?

1. Raising fluids a fixed distance through a pair of rotating screws
2. Raising a fluid between points located on different levels
3. Transferring a fixed amount of fluid with each revolution of its shaft
4. Transferring fluids between two fixed points located on the same level

10-17. Slippage in a rotating pump refers to the

1. leakage of liquid being pumped from the discharge to the suction side of the pump
2. loss in capacity due to viscosity of the liquid being pumped
3. clearance between the moving and stationary parts
4. improper assembly of the pump parts

10-18. An advantage of the herringbone gear pump over the simple gear pump is that the herringbone is capable of

1. maintaining a steadier speed
2. producing a smoother discharge flow
3. operating for longer periods of time
4. delivering liquids over greater distances

10-19. In the helical gear pump, what prevents metal to metal contact of the teeth?

1. The roller bearings
2. The timing gear
3. A stuffing box
4. A helical gear

For the helical pump, in items 10-20 and 10-21 match the function in column A with the part in column B.

	A. Function	B. Part
10-20.	Maintain alignment	1. Timing gear
10-21.	Prevent leakage at shaft	2. Roller bearings
		3. Stuffing box
		4. Helical gear

10-22. Which type of pump has two pairs of screws mounted on two parallel shafts, one shaft driving the other through a set of herringbone gears?

1. High pitch, double-screw pump
2. High pitch, triple-screw pump
3. Low pitch, double-screw pump
4. Low pitch, triple-screw pump

10-23. The pitch of the screws in the triple-screw, high-pitch pump is longer than in the low-pitch, double-screw pump.

10-24. In the triple-screw, high-pitch pump, what design feature enables the center screw to act as the power or driving rotor and eliminates the need for timing gears?

1. Location of the suction inlets and discharge parts
2. Difference in diameter of the center screw and the idlers
3. Shorter pitch of the screws
4. Longer pitch of the screws

- The starting procedure for a rotary pump contains the following steps.

A. Open pump discharge valve

B. Fill oil cups, check oil level

C. Open pump suction valve

D. Start the drive motor

E. Check the lubricating pressure

F. Open valves on pump pack gland seals

G. Lift all relief and sentinel valves by hand

10-25. Arrange the steps in the starting procedures of a rotary pump in sequence.

1. E, F, G, A, C, D, B
2. G, B, F, A, C, E, D
3. B, F, G, A, C, D, E
4. B, F, G, C, A, E, D

10-26. You are placing in operation a positive-displacement rotary pump that has a valve on the packing gland seal. Which of the following steps do you take after starting the driving unit?

1. Close the valve on the pump packing gland seal
2. Check the lubricating system to ensure proper pressures and lubrication of all bearings
3. Close the check valve on the discharge side of the pump to prevent overspeeding
4. Close the pump discharge valve

10-27. You have started a rotary pump but it does not build up a normal pressure. You stop the pump, inspect all the valves, and start the pump again. After the pump is running at its correct speed, the vacuum gage reads only 6 inches of mercury. The failure of the pump to build up a normal pressure is caused by

1. an obstruction in the suction lines
2. air leaking into the pump suction
3. an open discharge line
4. failure to prime the pump

10-28. If a fuel oil tank drain pump is being tested with the suction valve closed, which of the following is an indication to replace wearing rings?

1. Pounding
2. Less than 6 inches of vacuum
3. 16 inches of vacuum
4. Lack of discharge

10-29. When checking thrust bearings and the rotor position of a pump, what allowance should you make?

1. For future wear of the bearings
2. For expansion of the shaft under hot running conditions
3. For slight misalignments
4. For looseness of the keys holding the rotors in the shafts fitted with timing gears

10-30. Assume that you are assigned to take care of a pump that is connected to its driving unit by a flexible coupling with self-contained lubricant. How can you reduce wear on the coupling?

1. Ensure that the pump and driving unit are properly aligned
2. Keep the coupling filled with lubricant
3. Do both 1 and 2 above
4. Ensure that the water flingers are tightly fitted to the pump shaft

10-31. Before you try to jack over a pump by hand you must be sure that the

1. throttle valve is open
2. exhaust valve is open
3. power is off
4. constant-pressure governor is properly set

10-32. A liquid is being transferred by means of a centrifugal pump. When the volute of the pump causes the velocity of the liquid to decrease, the result is a/an

1. decrease in pressure
2. increase in pressure
3. decrease in potential energy
4. increase in kinetic energy

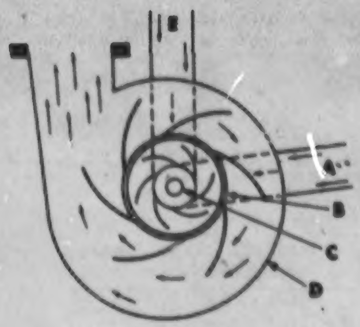

Figure 10-A

10-33. When water is being pumped, the function of the diffuser vanes in figure 10-A is to

1. increase the velocity of the water
2. distribute the water among the impeller blades
3. decrease the velocity of the water
4. diffuse heat produced by the pump

10-34. Since a double-suction impeller of a centrifugal pump serves to admit fluid from two directions, it can be classed as a multistage pump.

10-35. Very close clearances between the impeller and the pump casing of a centrifugal pump are necessary to

1. prevent excessive wear without reducing the operating speed of the pump
2. afford proper lubrication without wasting lubricating oil
3. prevent the pump from becoming vapor-bound
4. keep liquid from leaking to the suction side from the discharge side

10-36. What feature of centrifugal pumps reduces the need for renewing worn impeller and pump casings?

1. Close radial clearance between impeller hub and casing
2. Low rotational speed of impeller
3. Removable end plate
4. Replaceable wearing rings

10-37. Which of the following devices are used to prevent overheating of a centrifugal pump when the pump discharge is completely shut off for extended periods?

1. Recirculating lines
2. Auxiliary outlets
3. Casing drains
4. Guide vanes

10-38. A slight trickle of water coming out of the stuffing box or seal of a centrifugal pump while the pump is in operation indicates

1. a scored shaft
2. a broken seal
3. proper seal lubrication
4. insufficient packing

10-39. What is the function of the water flingers installed on centrifugal pump shafts near the stuffing box gland?

1. They prevent the packing from drying out
2. They keep the stuffing box packing compressed
3. They keep the fit between the shaft and the shaft sleeves tight
4. They keep water from running along the shaft and getting into the bearing housings

10-40. Misalignment of the driving and driven units connected by a flange coupling is indicated by which of the following symptoms?

1. Abnormal noises
2. Worn bearings
3. Abnormal temperatures
4. Any of the above

10-41. When using a 6-inch scale or a thickness gage to check pump alignment, at what intervals around the flanges of a shaft coupling should you measure?

1. 60°
2. 90°
3. 120°
4. 180°

10-42. Assume that the water pump used in the cooling system of a large diesel engine begins to vibrate. Which of the following troubles would you suspect as a possible cause?

1. Unbalanced impeller due to partial clogging
2. Air in the water
3. Insufficient speed
4. Incorrect discharge valves open in manifold

10-43. The casing and impeller wearing rings of a centrifugal pump serve to

1. minimize internal bypassing of fluid
2. house the impellers
3. prevent air from being drawn into the suction line
4. reinforce the impellers and prevent undue wear and strain

10-44. Excessive wear of the casing wearing ring and impeller ring of a centrifugal pump is caused by operating the pump with

1. badly scored shaft sleeves
2. excessive discharge pressure
3. high vacuum
4. a badly worn sleeve bearing

10-45. You can distinguish between (A) the radial-piston variable stroke pump and (B) the axial-piston variable stroke pump by comparing

1. driving units: (A) uses a steam turbine, (B) uses an electric motor
2. types of piston motions: (A) has reciprocating, (B) has rotary
3. piston arrangements around the pump shaft: (A) is like the spokes of a wheel, (B) is like the cylinder of a fully loaded revolver
4. directions of shaft rotation: (A) turns clockwise, (B) turns counterclockwise

10-46. When the tilting block of a rotating axial-piston variable stroke pump is NOT at right angles to the shaft, which of the following conditions exists?

1. Liquid is being pumped
2. Liquid is not being pumped
3. Pump pistons are rotating about the main shaft
4. Pump pistons are not reciprocating inside their cylinders

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10-47. To decrease the amount of flow of a radial-piston variable stroke pump, it is necessary to change the position of the

1. tilting box
2. floating ring
3. electric motor control
4. central cylinder valve

10-48. Which part of a jet pump must be replaced as a result of excessive wear?

1. Discharge line
2. Nozzle
3. Suction line
4. Suction chamber

Learning Objective: Identify different types of valves with their maintenance procedures and applications. Textbook pages 326 through 331.

10-49. Before repairing the seat and disk of a globe valve, you should determine that which of the following conditions are met?

1. The valve stem is straight
2. The disk is secured rigidly to the valve stem
3. The disk is square on the valve stem
4. All the above

10-50. In which of the following processes do you remove slight irregularities from the seat and disk of a globe valve by applying abrasive compound to the disk, then rotating the disk back and forth over the seat?

1. Spotting-in
2. Grinding-in
3. Lapping
4. Refacing

10-51. By what process, if any, can over-grinding of a valve seat or disk be corrected?

1. Machining
2. Lapping
3. Spotting
4. None

10-52. With which of the following repair processes are approved abrasive compounds used to recondition seats and disks of globe valves?

1. Machining
2. Filing
3. Refacing or reseating
4. Lapping or grinding-in

10-53. How wide is the valve seat of a 3-inch valve?

1. 1/16 in.
2. 3/32 in.
3. 1/8 in.
4. 3/16 in.

10-54. The second digit of the four digit symbol used by Naval Sea Systems Command to identify packing represents the

1. class of service of the packing
2. style of the packing
3. composition of the packing
4. form of the packing

10-55. To ensure the longest period of usefulness, you should operate a gate valve in which position?

1. Partly opened
2. Fully opened
3. Fully closed
4. Either 2 or 3 above

10-56. Which of the following methods should you use to recondition the lightly pitted seat of a gate valve in a piping system?

1. Remove the valve from the system and lap the seat until it is smooth and even
2. Remove the valve from the system and machine to produce a smooth finish
3. Leave the valve in the system and lap the seat until it is smooth and even
4. Leave the valve in the system and machine no more of the seat than is necessary to produce a smooth finish

10-57. When a plug-cock valve in a cooling system is being lubricated, what precaution must be taken to prevent the lubricant from being forced into the water stream?

1. The check valve must be partially open
2. The check valve must be either wide open or completely closed
3. The engine must be completely stopped
4. The pressure of the cooling system must be low

10-58. Which of the following kinds of valves are usually used to maintain an even lubricating oil pressure as an engine changes speed?

1. Check valves
2. Pressure-regulating valves
3. Plug-cock valves
4. Gate valves

10-59. By what means is the resilient seat of the butterfly valve held in place?

1. Compression
2. Cementing or bonding
3. Spring pressure
4. Setscrews

10-60. You can return a fully opened butterfly valve to its fully closed position by

1. depressing a pushbutton
2. turning the handle one-fourth of a turn
3. lifting up on the handle and releasing it quickly
4. pushing in on the handle and holding it in position for a second

Assignment 11

Compressed Air Systems and Distilling Plants

Textbook Assignment: Pages 332 through 360

Learning Objective: Point out the classifications, operating principles, and functions of air compressors and identify their component parts. Textbook pages 332 through 348.

11-1. Aboard Navy ships, compressed air is used for which of the following?

1. Charging and firing torpedoes
2. Starting steam turbines
3. Operating hydraulic tools
4. All of the above

11-2. Air compressors are classified as single-acting, double-acting, single-stage, multistage, horizontal, angle, and vertical. The compressor shown in view E, figure 16-1, of your textbook is classified as

1. multistage
2. horizontal
3. double-acting
4. angle

11-3. When compression takes place in both strokes per revolution of a cylinder, the compressor is classified as

1. single-stage
2. multistage
3. single-acting
4. double-acting

11-4. Which type of air compressor is generally selected when the capacity and pressure requirements are 2,000 cfm and 80 psi respectively?

1. Centrifugal
2. Reciprocating
3. Rotary
4. Each of the above

11-5. What is the usual source of power of operating air compressors aboard ship?

1. Steam turbines
2. Internal-combustion engines
3. Electric motors
4. Reciprocating steam engines

11-6. What device is generally used to connect the source of power to an air compressor when the speed of the driving unit and compressor is the same?

1. Rigid coupling
2. Flexible coupling
3. V-belt
4. Reduction gear mechanism

11-7. A medium-pressure air compressor is classified as

1. two-stage, vertical V-type, with a discharge pressure of 150 psi or less
2. two-stage, vertical, duplex, single-acting, with a discharge pressure of 151 psi to 1,000 psi
3. three-stage, vertical, single-acting with a discharge pressure of 1,500 psi or higher
4. three-stage, vertical, double-acting with a discharge pressure of 1,500 psi to 10,000 psi

11-8. Which cylinder arrangement is used in two stage, W-type air compressors?

1. One cylinder per stage
2. Two cylinders per stage
3. One cylinder for the first stage, two cylinders for the second stage
4. Two cylinders for the first stage, one cylinder for the second stage

11-9. How many strokes does a piston make in its cylinder during each operating cycle of a single-stage, single-acting air compressor?

1. One
2. Two
3. Three
4. Four

11-10. The air inlet valve of a single-stage single-acting reciprocating air compressor is forced open by the

1. movement of the piston as it starts the suction stroke
2. movement of the piston as it starts the compression stroke
3. the difference in pressure produced by the piston as it moves away from TDC
4. difference in pressure produced by the piston as it moves toward TDC

11-11. When does cylinder pressure force open the discharge valve of a single-stage, single-acting reciprocating air compressor?

1. When the piston is nearing the end of a suction stroke
2. When the piston is nearing the end of a compression stroke
3. When the piston is starting a suction stroke
4. When the piston is starting a compression stroke

11-12. The compressing element of an air compressor includes all of the following parts EXCEPT the

1. cylinder
2. piston
3. air valves
4. unloader

11-13. The operation of the automatic valves of an air compressor is initiated by

1. an air pressure differential
2. a lack of air pressure
3. a high air pressure
4. a camming action

11-14. What is the advantage of fitting an air compressor with a differential piston-and-cylinder arrangement?

1. More even distribution of side pressure
2. Less heat of compression to dissipate
3. Single-stage compression by a lighter compressing element
4. Multistage compression by one piston

11-15. What device is used to lubricate the high-pressure air compressor cylinders?

1. Cylinder splash lubricator
2. Compressor oil pump
3. Adjustable mechanical force-feed lubricator
4. Sight-glass oil flow indicator

11-16. A feed line check valve prevents compressed air from forcing lube oil back into the forced-feed lubricator of an air compressor.

11-17. The cylinder lubricator must be started before the air compressor starts up.

11-18. What is the flow path of lube oil for the running gear in a modern air compressor?

1. Oil sump to filter to cooler, then to main bearings, spray nozzles, and outboard bearings
2. Oil sump to cooler to main bearings, then to filter, spray nozzles, and outboard bearings
3. Filter to cooler to sump, then to main bearings, spray nozzles, and outboard bearings
4. Filter to sump to cooler, then to main bearings, spray nozzles, and outboard bearings

11-19. What is the cooling medium for most high- and medium-pressure air compressors aboard ship?

1. Oil
2. Seawater
3. Freshwater
4. Either 2 or 3 above

11-20. Why are cylinders and heads of some shipboard air compressors made of bronze alloy?

1. To promote cooling
2. To reduce wear
3. To minimize corrosion
4. To do all of the above

11-21. What is the function of the intercoolers of an air compressor?

1. To remove heat generated during compression and to condense existing vapor
2. To remove heat from the incoming water and to condense existing vapor
3. To cool the air before compression
4. To cool the air after the final stage of compression

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11-22. The advantages of interstage cooling in an air compressor include which of the following?

1. Increased effectiveness in piston and valve lubrication
2. Reduction in amount of power required to run the compressor
3. Reduction in amount of heat to be removed by the cylinder jackets
4. All of the above

11-23. Baffles are used in a straight shell-and-tube type of water-cooled intercoolers to

1. remove oil contaminants from the air
2. deflect air or water passing through the cooler
3. prevent the tube nest from expanding
4. prevent the tube nest from contracting

11-24. By what means do the separators in compressor intercoolers and aftercoolers remove moisture and oil from the air stream?

1. Centrifugal force
2. Impact
3. Sudden changes in velocity
4. All of the above means

11-25. The quantity of water that passes through the oil cooler can NOT be regulated without changing the quantity that passes through the intercoolers.

11-26. To which parts of a compressed air cooling system are temperature-detecting devices fitted?

1. Circulating water inlet and outlet connections
2. Intake and discharge of each stage of compression
3. Final air discharge and oil reservoir
4. All of the above

11-27. The control system for an electrically driven reciprocating air compressor will stop the compressor automatically when the pressure in the receiver causes a

1. governor valve to open
2. governor valve to close
3. pressure switch to open
4. pressure switch to close

11-28. The automatic temperature shutdown device of a high-pressure reciprocating air compressor functions to stop the compressor when the

1. accumulator temperature rises a predetermined amount
2. accumulator temperature drops a predetermined amount
3. cooling water temperature rises above a preset limit
4. cooling water temperature drops below a preset limit

11-29. What is the function of the automatic unloading system on an air compressor unit?

1. To remove the compression load while it is starting
2. To apply the compression load after it reaches operating speed
3. To do both 1 and 2 above
4. To remove the friction load after it is started

11-30. Which of the following methods is used to unload an air compressor?

1. Holding intake valves closed
2. Closing cylinder clearance pockets
3. Venting intercoolers to the atmosphere
4. Each of the above

11-31. The rotary-centrifugal compressor is usually used to supply

1. high-pressure, nonoil-free air
2. low-pressure, oil-free air
3. high-pressure, oil-free air
4. low-pressure, nonoil-free air

11-32. Which of the following causes the air to compress in the rotary-centrifugal compressor?

1. Water
2. Centrifugal force
3. Impeller
4. Piston

11-33. Which of the following is a function of the air receiver in an air compressor system?

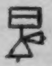
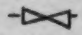
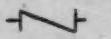
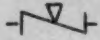
1. To cool the air
2. To reduce pressure variations
3. To do both 1 and 2 above
4. To filter the air of moisture and oil

11-34. Vertically mounted receivers have concave bottoms to permit draining.

11-35. When two or more air flasks are connected together they constitute a manifold.

Learning Objective: Identify piping symbols and trace compressed air lines as well as point out the effects of throttling. Textbook pages 348 through 350.

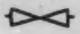
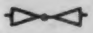
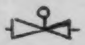
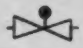
11-36. Which of the following is a relief valve?

1. 
2. 
3. 
4. 

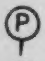
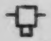
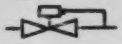
11-37. In figure 16-15A of the text, what is the air pressure of the ship's service low-pressure air?

1. 3,000 psi
2. 150 psi
3. 168 psi
4. 180 psi

11-38. Which of the following is the symbol for a locked open globe valve?

1. 
2. 
3. 
4. 

11-39. Which of the following is the symbol for a differential pressure gage?

1. 
2. 
3. 
4.

11-40. Which of the following systems is supplied nonvital air?

1. Automatic boiler control
2. Water level control
3. Air pilot-operated control valves
4. Laundry equipment

11-41. What type of compressor is used to supply air to the prairie-masker system?

1. Turbocompressor
2. Multistage compressor
3. Angle compressor
4. Vertical compressor

11-42. When a large volume of high-pressure air is throttled to a low pressure, the throttling valve may become frozen. What causes the freezing?

1. Charles' effect
2. Venturi effect
3. Herbst effect
4. Boyle's effect

11-43. What type of dryer or desiccant dehydrator does NOT require heat or a separate heat source?

1. Boss' dryer
2. Mueller's dryer
3. Heat-Les dryer
4. Heat-Lyn dryer

Learning Objective: Identify effective inspection and maintenance procedures, troubleshooting procedures, and applicable safety precautions. Textbook pages 351 through 354.

11-44. The Maintenance Index Page (MIP) indicates the various maintenance tasks, the rating responsible for performing the tasks, and the time required for the tasks. How long should it take to clean the air intake filter?

1. 1.0 man-hour
2. 0.2 man-hour
3. 0.5 man-hour
4. 1.5 man-hours

11-45. When an air compressor is operating, how often should the crankcase oil level be checked?

1. Hourly
2. Every 4 hours
3. Every 24 hours
4. Weekly

11-46. Rapid pressurization with high-pressure air may generate heat high enough to ignite oil and other impurities.

11-47. Which of the following safety precautions should you observe before starting to work on an air compressor?

1. Blow down the compressor
2. Secure all valves between the compressor and receiver
3. Make sure compressor cannot be started
4. All of the above

11-48. The use of gasoline or a similar liquid to clean compressor intake filters is prohibited because the liquid has the ability to do which of the following?

1. Reduce the efficiency of the filters
2. Damage the filter material
3. Vaporize easily and form a highly explosive mixture with the air under compression
4. Do all of the above

Learning Objective: Specify operating principles and functions of components of the submerged tube distilling plant. Textbook pages 355 through 360.

11-49. A steam-operated distilling plant produces distilled water from seawater through the use of an evaporation process followed by condensation.

11-50. Naval distilling plants are NOT able to remove all biological contaminants.

11-51. Distilling plants are able to separate all volatile fluids from distillate.

11-52. Distilling plants will destroy all microorganisms because the water is hot enough to kill them.

11-53. Because of carryover, saltwater in the distillate is most likely caused by

1. faulty salinity cells
2. leaks in the tube nests
3. leaks in the basket
4. improper operation

11-54. Why is carryover undesirable?

1. Chemical salts cause corrosion of boiler tubes
2. Coliform bacteria may be present
3. The distillate is not sterilized
4. Each of the above is correct

11-55. Why are Navy distilling plants operated at low pressure?

1. To prevent carryover
2. To increase efficiency
3. To sterilize the distillate
4. Each of the above is correct

In items 11-56 through 11-58 select the term from column B that is defined in column A.

	A. Definition		B. Term
11-56.	The end product of an evaporator	1.	Distillation
		2.	Evaporation
11-57.	The saltwater that is boiled to produce a vapor	3.	Feed
		4.	Distillate
11-58.	The process of separating seawater into vapor and brine		

In items 11-59 through 11-61 select the term from column B that is defined in column A.

	A. Definition		B. Term
11-59.	A measurement of the concentration of chemical salts	1.	Brine
		2.	Salinity
11-60.	The stage of an evaporator	3.	Effect
		4.	Evaporator feed
11-61.	Any water in which the salt content is higher than it is in seawater		

11-62. What is the degree of superheat of steam at 100.82°C with 23.81 in. Hg gage?

1. 60.82°C
2. 50.22°C
3. 30°C
4. 40°C

11-63. The vapor compressor type evaporator uses electrical energy to heat the water and to operate the compressors.

11-64. Which of the following ships have vapor compression distilling units?

1. Aircraft carriers
2. Frigates
3. Submarines
4. Destroyers

11-65. Why are the low-pressure distilling units called low pressure?

1. Because they use low-pressure steam
2. Because they operate below atmospheric pressure
3. Because of both 1 and 2 above
4. Because of the low pressure on the feed

11-66. In the submerged tube evaporator the tubes contain

1. feed
2. low-pressure steam
3. brine
4. distillate

11-67. In the Soloshell evaporator, which of the following controls the amount of steam admitted to the tubes?

1. Relief valves
2. Reducing valve
3. Each of the above
4. Orifice plate

● When answering items 11-68 through 11-75, refer to figure 17-3 in your textbook.

11-68. Which device maintains a pressure of approximately 5 psi to the tube nest of the first-effect evaporator?

1. Relief valve
2. Orifice valve
3. Spring-loaded back-pressure valve
4. Reducing valve

11-69. The volume of distilled water produced by the plant depends on the

1. setting of the regulating valve in the exhaust steam line to the first-effect evaporator
2. size of the orifice plate in the exhaust steam line to the first-effect evaporator
3. capacity of the vapor feed heater in the first-effect shell
4. number of baffles in the vapor separator of the second-effect shell

11-70. To which process is low-pressure exhaust steam subjected before it passes into the first-effect tube nest?

1. Heating by steam from the 150-psi system
2. Superheating by a spray of water
3. Desuperheating by a spray of water
4. Volume reducing by increased steam pressure

11-71. Condensate from the first-effect tube nest is pumped to the

1. distillate cooler
2. vapor feed heater
3. air ejector condenser
4. freshwater drain tank or the main or auxiliary condenser

11-72. The condensate from the first-effect tube nest which is returned to the boiler feed system is used to

1. generate vapor from the feedwater in the second-effect evaporator shell
2. provide feed to the first-effect evaporator
3. desuperheat the auxiliary exhaust steam
4. help stabilize the heat and water content of the system

11-73. Steam generated in the evaporator shells by the evaporation of feedwater is referred to as

1. distillate
2. vapor
3. superheat
4. drain

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11-74. What is the purpose of the baffles and vanes in the evaporator shell?

1. To cool off the vapor
2. To slow down the vapor
3. To separate small amount of unevaporated feedwater from the vapor
4. To desuperheat the vapor

11-75. Before entering the second-effect evaporator, vapor from the first-effect separator passes into the

1. first-effect drain regulator
2. vapor feed heater
3. boiler feed system
4. freshwater tanks

Assignment 12

Distilling Plants (Continued)

Textbook Assignment: Pages 360 through 385

Learning Objective (Continued): Specify operating principles and functions of components of the submerged-tube distilling plant. Textbook pages 360 through 363.

● When answering questions 12-1 through 12-11 refer to figure 17-3 of the textbook.

12-1. What change takes place in the first-effect vapor when it reaches the tube nests of the second-effect evaporator?

1. It gains latent heat of vaporization from the second-effect feed
2. It gains latent heat of vaporization from a second-effect steam supply
3. It loses its latent heat of vaporization to the second-effect feed
4. It loses its latent heat of vaporization to a second-effect steam supply

12-2. Why is first-effect vapor able to boil and vaporize the seawater feed in the second-effect shell?

1. Pressure is higher in the first-effect shell than in the second-effect shell
2. Pressure is lower in the first-effect shell than in the second-effect shell
3. Vapor and distillate are superheated on entering the second-effect shell
4. Vapor and distillate are desuperheated on entering the second-effect shell

12-3. Latent heat of vaporization given off in the distilling condenser is used to

1. desuperheat incoming vapor
2. boil feedwater in the first-effect shell
3. heat incoming seawater
4. superheat vapor in the first-effect separator

12-4. The distillate pump is used to pump the distillate from the flash chamber to which of the following?

1. Feedwater tank
2. Test bank
3. Potable water system
4. Each of the above

12-5. What happens to the seawater that passes through the tubes of the distilling condenser?

1. All is discharged overboard
2. All is directed to the boiler feed system
3. Part is used as first-effect feed; the rest is discharged overboard
4. Part is directed to the boiler feed system; the rest goes to the second-effect shell

12-6. After entering the first-effect shell, some of the feedwater is evaporated. The rest of the feedwater (brine) is forced into the second-effect shell by

1. gravity
2. the condenser circulating pump
3. the pressure difference between the first effect and second effect
4. a tube-nest drain pump

12-7. What means is provided to permit the first- and second-effect shells to be drained rapidly?

1. Regulating valves in the piping
2. Perforated pipes in each effect
3. Portable pump connections
4. Suction connections leading directly to the brine overboard pump

12-8. What is the function of the circulating water at the brine overboard pump?

1. To provide cooling
2. To dilute the brine
3. To seal the gland
4. Each of the above is correct

12-9. Which of the following maintains the vacuum in the second effect?

1. Air ejector
2. Condensation of steam in the vapor feed heater
3. Cooling effect of carbon dioxide
4. Steam condensed by the evaporator feed

12-10. A salinity cell is located at the discharge of the tube nest drain pump. Where is the tube nest drain pump located in figure 17-3 of the textbook?

1. Lower right-hand side
2. Upper right-hand side
3. Lower left-hand side
4. Upper left-hand side

12-11. Salinity cells are installed in a pipe fitting similar to a thermometer well.

- When answering items 12-12 through 12-17, assume that you are to start a manually controlled low-pressure submerged-tube distilling plant that has been totally secured.

12-12. Which of the following steps of procedure must you perform before starting the evaporator feed pump?

1. Regulate spring-loaded back-pressure valve in circulating water overboard line
2. Open air ejector suction valve
3. Start the first-effect tube-nest drain pump
4. Start the brine overboard pump

12-13. Which of the following valves do you leave closed after placing the brine overboard pump in operation?

1. Valve in the emergency circulating water line from the air ejector condenser
2. First-effect tube-nest vent valve
3. Second-effect tube-nest vent valve
4. Air ejector suction valve

12-14. After distillate appears in the flash chamber gage glass, the next step is to open the valve at the

1. first-effect tube-nest
2. distillate pump suction
3. freshwater system
4. water meter

12-15. Which of the following steps should be performed after the freshwater pump is started and sufficient feedwater is flowing through the air ejector condenser?

1. Draw off enough distillate for testing
2. Close off the emergency circulating water valve on the air ejector condenser
3. Open the distillate pump suction valve
4. Adjust feed valves

12-16. When should the density of the brine discharge be checked?

1. Before the desired second-effect vacuum has been reached
2. Before the desired first-effect steam pressure has been reached
3. After the desired first-effect steam pressure and the second-effect vacuum have been reached
4. After the distillate is shifted to the bilges because of high salinity

12-17. When proceeding to secure a manually controlled low-pressure distilling plant, you open the drain to the bilges after

1. securing the exhaust steam to the first-effect tube-nest
2. closing the first-effect tube-nest vent valve
3. securing the freshwater pump
4. securing the steam to the air ejector

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Learning Objective: Explain the salinity testing requirements for distilling plants. Textbook pages 365 through 368.

12-18. The chemical and electrical salinity tests are the two methods by which an operator can check the purity and chloride content of the distillate.

12-19. A salinity test reading of 3 epm for a solution of table salt is equivalent to a concentration of

1. 35.5 ppm
2. 58.5 ppm
3. 152.5 ppm
4. 175.5 ppm

12-20. What should you do if the salinity indicator you are checking reads 2.5 grains while the test button is depressed?

1. Calibrate the indicator
2. Place the indicator in operation
3. Calibrate the indicator, then place it in operation
4. Have an IC Electrician check the indicator

12-21. How often must the water in the measuring and testing tanks be sampled and tested chemically for salinity?

1. Each time 50 gal of distillate is pumped into the tank
2. Once an hour
3. Each time 25 gal of distillate is pumped into the tank
4. Once a day

12-22. You are running a salinity test by the chemical method. What color should the sample be when you finish adding mercuric nitrate to the solution?

1. Pale yellow
2. Pale green
3. Pale blue-violet
4. Bright red

12-23. What chloride limit shall NOT be exceeded in the condensate of the main condenser?

1. 0.05 epm
2. 0.5 epm
3. 1.0 epm
4. 1.5 epm

Learning Objective: Identify operating requirements for distilling plants. Textbook pages 368 through 375.

12-24. Why is it desirable to maintain a steam pressure of 5 psig above the orifice which controls steam flow to the first-effect tube-nest?

1. To eliminate the need for salinity tests
2. To reduce the density of the brine
3. To maintain constant distilling plant output
4. To lighten the watchstander's duties

12-25. Assume that 280°F steam is below the orifice that controls steam flow to the first-effect tube-nest. Water for desuperheating the steam is taken from the

1. freshwater drains
2. reserve feedwater tanks
3. discharge side of the first-effect tube-nest drain pump
4. discharge side of the distilling plant's distillate pump

12-26. If an evaporator unit is operated at rated capacity for an extended period of time with approximately 12 inches of vacuum, which of the following conditions will result?

1. An increase in the operating temperatures
2. An increase in the rate of scaling of the tube-nests
3. Both 1 and 2 above
4. A decrease in the amount of scale deposited on the tube-nests

12-27. A rapidly fluctuating last-effect shell vacuum is likely to cause

1. an inadequate flow of circulating water
2. a reduction in the efficiency of heat transferring surfaces
3. priming
4. a reduction in the efficiency of air ejectors

12-28. The most common cause of low vacuum in a distilling plant shell is

1. air leakage
2. excess steam pressure
3. faulty mechanical operation
4. overheating

12-29. What weight of seawater upon evaporation should yield about 1 pound of salts?

1. 16 lb
2. 32 lb
3. 48 lb
4. 64 lb

12-30. The usual effect of too high a brine concentration in the evaporator is an increase in the

1. rate of distillate formation
2. amount of brine pumped overboard
3. pressure of the steam line
4. rate of evaporator tube scaling

● Items 12-31 through 12-39 pertain to a two-stage, flash-type distilling plant. Refer to figure 17-9 in your textbook.

12-31. Feedwater for the distilling plant is preheated before reaching the feedwater heater as it circulates through which of the following units?

1. The distillate cooler
2. The air ejector condenser
3. The stage distilling condensers
4. All of the above

12-32. As feedwater passes through the evaporator feedwater heater, final heating of the feed is done by

1. an electric heater
2. auxiliary exhaust steam
3. high-pressure steam
4. brine overflow

12-33. Heated feedwater enters the first-stage shell by way of spray pipes located in the

1. stage distilling condensers
2. stage vapor separators
3. bottom of the first-stage shell
4. second-stage internal feed box

12-34. Unvaporized feedwater in the first-stage flash chamber passes to the

1. brine overboard line
2. evaporator feedwater heater
3. second-stage shell
4. low-pressure drain system

12-35. Why does the heated seawater vaporize in the shells of the distilling plant?

1. Pressure in the shell is higher than the saturation pressure corresponding to the temperature of the seawater
2. Pressure in the shells is lower than the saturation pressure corresponding to the temperature of the seawater
3. Temperature of the seawater is decreased
4. Pressure in the shell is higher than atmospheric pressure

12-36. Brine from the second-stage shell is discharged to the

1. brine overboard line
2. evaporator feedwater heater
3. first-stage flash chamber
4. low-pressure drain system

12-37. The water from the demisters of the first stage drains to the

1. distillate of the first stage
2. feed section of the first stage
3. feed section of the second stage
4. hotwell

12-38. When the distilling plant is being started, to which process is supply steam subjected before it enters the shell of the evaporator feedwater heater?

1. Heating by steam from a 150-psi system
2. Superheating by a spray of cold water
3. Desuperheating with water from the feedwater heater
4. Desuperheating with water from the ship's condensate system

12-39. In the two-stage flash type evaporator, where are the two three-way solenoid trip valves located?

1. At the loop seal and the distillate pump
2. At the loop seal and the air ejector drain
3. At the distillate pump outlet and the air ejector drain
4. At the seawater heater drain and at the loop seal

12-40. What is the maximum design feedwater temperature?

1. 75°F
2. 85°F
3. 165°F
4. 175°F

12-41. How can the capacity of a flash-type evaporator be increased?

1. Increase the volume of feed to the first stage
2. Increase the heat of the feedwater
3. Decrease vacuum in the first stage
4. Decrease the heat of the feedwater

Learning Objective: Point out operating principles of the vertical basket distilling plant and specify functions of the components. Textbook pages 375-379

12-42. The corrugated basket and evaporator shell are one and the same shell.

12-43. The fluid between the basket and the shell in the first-effect of the distilling plant has been previously heated by the

1. auxiliary boiler
2. second-effect basket
3. vapor feed heater
4. second-effect steam dome

12-44. Vapor is generated in the second-effect shell as a result of the second-effect feed being heated by the

1. first-effect vapor
2. feedwater heater
3. brine drains
4. steam supply

12-45. What device is used in some vertical-basket type distilling units to prevent vapor locking of the distillate pump?

1. Loop seal
2. Condensate drain
3. Cyclonic separator
4. Drain collector

12-46. The salinity of the distillate produced by the plant under normal operating conditions will be less than 0.065 epm.

Learning Objective: Describe the construction and function of heat recovery type distilling units. Textbook pages 379-381.

12-47. In the heat recovery type distilling unit, the evaporation temperature is maintained by which of the following means?

1. Tube bundle
2. Air eductor
3. Jacket water
4. Vapor

12-48. The feedwater level in the evaporator is controlled by an internal weir-type controller.

12-49. Noncondensable vapors collect in the distillate condenser because of which of the following conditions?

1. Lower temperature
2. Higher temperature
3. Lower pressure
4. Higher pressure

12-50. In the heat recovery distilling unit, the jacket water makes how many passes through the tube bundle?

1. One
2. Two
3. Three
4. Four

12-51. The jacket water circuit provides how much water per minute and at what temperature in the tube bundle?

1. 100 gpm at 100°F
2. 200 gpm at 150°F
3. 300 gpm at 180°F
4. 400 gpm at 200°F

12-52. After startup what is the primary function of the air and brine eductor?

1. To remove noncondensables from the jacket water
2. To remove noncondensables from the brine
3. To remove noncondensables from the shell interior
4. To remove noncondensables from the distillate cooler

Learning Objective: Specify and identify methods and techniques to be used in maintenance, feedwater treatment, and cleaning of the distilling plants. Textbook pages 381 through 386.

12-53. Scale deposits on the evaporator tubes of a submerged-tube distilling plant will cause a reduction in output which becomes measurable when the deposits reduce the first-effect, tube-nest vacuum to

1. 1 or 2 inches of mercury
2. 4 or 6 inches of mercury
3. 8 or 10 inches of mercury
4. 12 or 14 inches of mercury

12-54. Under normal operating conditions, what is the usual interval between cleaning of air ejector condenser tubes?

1. 3 months
2. 6 months
3. 9 months
4. 12 months

12-55. In a distilling plant that uses seawater feed, what condition should be maintained to keep the formation of hard scale to a minimum?

1. Steam pressure above orifice not to exceed 5 psi
2. High vacuum
3. Brine density not to exceed 1.5 thirty-seconds
4. Each of the above

12-56. Evaporator feedwater is treated with PD-8 for the purpose of reducing the

1. rate of tube scaling
2. amount of insoluble suspended matter
3. quantity of soluble carbonates
4. priming

12-57. PD-8 solution is prepared by dissolving the required amount of PD-8 in warm water and diluting it with enough cold water to make a batch totaling

1. 12 gal
2. 18 gal
3. 24 gal
4. 30 gal

- Items 12-58 through 12-63 pertain to the procedure for injecting chemicals into the distilling plants.

12-58. A duplex pump may be used to inject chemicals into two separate distilling plants when the plants

1. are in different compartments
2. vary in output by not more than 4,000 gpd
3. are in separate compartments but have equal distilling capacity
4. are equal in distilling capacity and are in the same compartment

12-59. You find that a pump stroke of 15% will be required to empty the mixing tank in 24 hours. You should adjust the stroke so that the tank will empty in

1. 4 or 8 hours
2. 8 or 12 hours
3. 12 or 16 hours
4. 16 or 20 hours

12-60. If the proportioner pump fails, the operator feeds the chemical solution into the evaporator by means of a vacuum injection line and controls the flow by the use of

1. a standby pump
2. a feed control valve
3. an adjusting screw
4. a needle valve

12-61. How much PD-8 is recommended for a 12,000 gpd submerged-tube type distilling plant?

1. 1.2 pounds every 24 hours
2. 1.5 pounds every 12 hours
3. 2.0 pounds every 24 hours
4. 2.6 pounds every 12 hours

12-62. You can determine how well the PD-8 feedwater treatment is functioning by

1. examining the evaporator for sludge
2. examining the evaporator for scale
3. checking the shell temperature in the feedwater heater
4. observing the condition of the mixing tank during draining and flushing

12-63. In accordance with the Planned Maintenance System, when will the mixing tank for PD-8 evaporator treatment be drained and flushed?

1. Quarterly
2. Weekly or more often if necessary
3. Annually
4. Monthly

12-64. What is an indication that the flash-type unit needs cleaning?

1. When a 4-psig steam pressure in the evaporator feedwater heater is required to produce rated capacity
2. When a 4-psig steam pressure in the first-effect steam chest is required to produce rated capacity
3. When the first-effect, tube-nest vacuum is near zero
4. When the first-effect, tube-nest temperature approaches that of the steam supply

12-65. Which of the tube nests of a distilling plant tends to collect scale most rapidly?

1. First-effect
2. Second-effect
3. Third-effect
4. Fourth-effect

12-66. How do you chill shock the first-effect evaporator tube-nest of a distilling plant?

1. Cut out steam flow to the tubes and quickly flood them with cold water
2. Cut out flow of water to the tubes and increase the flow of steam
3. Drain brine from the shells and admit water into the tubes
4. Drain brine from the shells, reflood them with water and admit steam into the tubes

12-67. How often should a distilling plant be chill shocked when no feed treatment is used?

1. Daily
2. Weekly
3. Semimonthly
4. Semiannually

12-68. After the tube nest has been removed from a submerged-tube type evaporator, the tubes are cleaned mechanically by a/an

1. electric torch
2. scaling tool
3. abrasive
4. electric vibrator

12-69. After cleaning and before placing the tube nest in service, you subject the bundle to a hydrostatic test of

1. 25 psi
2. 50 psi
3. 75 psi
4. 100 psi

12-70. Which of the following types of distilling plants has a minimum amount of scale formation?

1. Vertical basket type
2. Submerged-tube double-effect type
3. Submerged-tube triple-effect type
4. Flash type

12-71. The acids commonly used for the chemical cleaning of evaporator parts are

1. nitric and sulfuric
2. sulfamic and nitric
3. hydrochloric and sulfamic
4. sulfuric and hydrochloric

12-72. Under which of the following conditions may sulfamic acid be stored safely aboard ship?

1. When transferred from original to special containers
2. When stored in original containers
3. When in solution form
4. Under all the above conditions

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Assignment 13

Refrigeration

Textbook Assignment: Pages 387 through 414

Learning Objective: Identify the terms related to principles of refrigeration and heat. Textbook pages 387 and 388.

13-1. Refrigeration is a general term that describes which of these processes?

1. Removing heat from spaces, objects, or materials
2. Allowing heat to flow in its natural direction, that is, from warmer material to the colder material
3. Both 1 and 2 above
4. Converting heat into work

13-2. How does a refrigeration unit freeze water?

1. It reduces the pressure of the water
2. It removes heat from the water
3. It adds coolness to the water
4. By doing both 2 and 3 above

13-3. The amount of heat removed from or added to a material is measured in terms of a standard unit called a

1. refrigeration ton
2. total heat
3. British thermal unit
4. sensible heat

For items 13-4 through 13-6, select from column B the definition or example that applies to the heat identification term in column A.

	A. Terms		B. Definitions or examples
13-4.	Sensible heat	1.	Heat absorbed by a man's body after he steps from a cold room into a warm room
13-5.	Latent heat	2.	Quantity of heat required to raise the temperature of unit mass of a substance
13-6.	Specific heat	3.	Heat absorbed by a block of melting ice
		4.	The ability of a substance to absorb or give off heat without change in temperature

13-7. What is the latent heat of fusion of a pound of ice?

1. 36 Btu
2. 72 Btu
3. 144 Btu
4. 288 Btu

13-8. Approximately how much heat must be removed from 1 ton of water at 32°F to change the water to ice at 32°F?

1. 36 Btu
2. 72 Btu
3. 12,000 Btu
4. 288,000 Btu

Learning Objective: Identify the basic relationship of pressure, temperature, and volume of a gas. Textbook pages 388 and 389.

13-9. At which of the following temperatures and pressures will water boil?

1. 100°F at 14.7 psia
2. 80°F at 29 in. vacuum
3. 450°F at 600 psig
4. Both 2 and 3 are correct

13-10. At which of the following temperatures and pressures will R-12 boil?

1. -20°F at 14.7 psig
2. -21°F at 14.7 psia
3. +45°F at 46.49 psig
4. Both 2 and 3 are correct

13-11. Before a confined quantity of vapor can be superheated, it must be

1. separated from the liquid from which it was generated
2. in contact with the boiling liquid
3. held at a constant pressure
4. allowed to decrease in volume

● For items 13-12 through 13-16 assume that a cylinder with a floating piston contains 5 cubic feet of air on each side (A and B) of the piston. The absolute air pressure on each side of the piston is 200 psi and the absolute temperature is 500°F.

13-12. If you pump air into side A to increase the pressure in side B to 250 psia, and constant temperature is maintained, what is the new volume in side B?

1. 7 cu ft
2. 6 cu ft
3. 5 cu ft
4. 4 cu ft

13-13. If you decrease the temperature in side A to 400°F absolute without changing its pressure, and with no increase in temperature in side B, what is the new volume in side A?

1. 7 cu ft
2. 6 cu ft
3. 5 cu ft
4. 4 cu ft

13-14. What is the effect of a 30°F temperature increase on both sides of the piston?

1. A small decrease in both pressure and volume
2. A small increase in both pressure and volume
3. A 12-psia decrease in pressure
4. A 12-psia increase in pressure

13-15. When the gas in a tank has an increase in temperature, the column will (a) and the pressure will (b)

1. (a) decrease, (b) decrease
2. (a) remain the same, (b) remain the same
3. (a) increase, (b) remain the same
4. (a) increase, (b) decrease

13-16. When the pressure on a gas increases, the temperature will (a); however, when the pressure decreases, the temperature will (b)

1. (a) rise, (b) lower
2. (a) lower, (b) rise
3. (a) lower, (b) remain the same
4. (a) remain the same, (b) lower

Learning Objective: Point out the most common type of refrigeration plant used aboard Navy ships, and identify the major components and their functions. Textbook pages 389 through 395.

13-17. What type of refrigeration system is generally used for shipboard refrigeration?

1. Vapor compression cycle with centrifugal compressors
2. Steam-jet systems with reciprocating compressors
3. Vapor compression cycle with reciprocating compressors
4. Steam-jet systems with centrifugal compressors

● Items 13-18 through 13-28 refer to figure 13A.

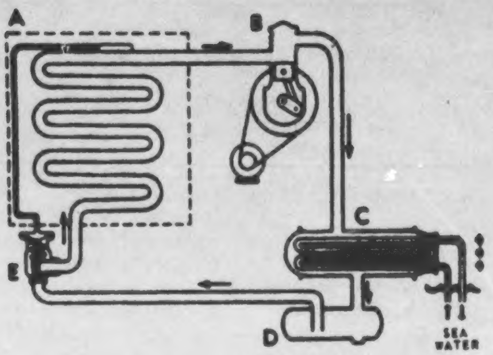

Figure 13A

13-18. Which of the following is the correct sequence of flow of refrigerant through the system?

1. Receiver, expansion valve, evaporator, compressor, condenser, receiver
2. Receiver, evaporator, expansion valve, condenser, compressor, receiver
3. Receiver, condenser, compressor, evaporator, expansion valve, receiver
4. Receiver, expansion valve, compressor, condenser, evaporator, receiver

13-19. Pressure of the liquid is reduced in part

1. B
2. C
3. D
4. E

13-20. Heat is absorbed by the R-12 refrigerant in part

1. A
2. C
3. D
4. E

13-21. R-12 is in liquid form in the system when it is between components

1. A and B
2. B and C
3. D and E
4. E and A

13-22. The low-pressure side of the refrigeration system lies between components

1. A and B
2. B and C
3. B and D
4. E and B

13-23. The operation of component E is controlled by a device located in component

1. A
2. B
3. C
4. D

13-24. What causes component E to open and permit the flow of liquid into A?

1. A decrease in pressure in the cooling coil
2. A decrease in pressure in the control bulb
3. An increase in pressure on the top of the diaphragm
4. An increase in pressure on the bottom of the diaphragm

13-25. What changes occur in the physical state of the R-12 as it passes through component A?

1. It changes from a boiling liquid to superheated vapor
2. It changes from superheated vapor to a boiling liquid
3. It changes from a cool liquid to a hot vapor
4. It changes from a hot vapor to a cool liquid

13-26. Which component pumps heat, absorbed by the refrigerant, from the evaporator to the condenser?

1. A
2. B
3. C
4. D

13-27. What is the primary function of component B?

1. To raise the temperature of liquid R-12 to the point where it will boil and vaporize completely before entering component C
2. To raise the pressure of liquid R-12 to the point where its temperature at this pressure is high enough to cause it to boil and vaporize completely before entering component C
3. To raise the pressure of vaporized R-12 to the point where its temperature at this pressure is high enough above the temperature of the cooling seawater to cool the R-12 and condense it as it passes through component C
4. To raise the pressure of vaporized R-12 to the point where its superheat at this pressure amounts to 10°F

13-28. What is/are a subsidiary function(s) of component B?

1. To condense the vapor
2. To keep the required pressure differential between the low side of the system and the high side
3. To circulate the R-12 through the system
4. To do both 2 and 3 above

Learning Objective: Identify the principles of operation of the accessories and controls for a refrigeration system. Textbook pages 395 through 405.

13-29. Where is the rotary seal, shown in figure 18-6 of the textbook, adjusted?

1. Between the crankshaft and the rotating carbon rings
2. Between the cover plate and carbon rings
3. Between the crankshaft shoulder and compression spring
4. Between the crankshaft and cover plate

13-30. Where is the stationary bellows seal, shown in figure 18-7 of the textbook, adjusted?

1. Between the crankshaft and the bellows
2. Between the crankshaft and the shaft seal collar
3. At the factory
4. Between the surface of the seal collar and bellows nose

13-31. In the rotating bellows seal, shown in figure 18-8 of the textbook, what is used to seal the surfaces between the removable shaft seal shoulder and the crankcase?

1. Neoprene gasket
2. Shaft seal clamping nut
3. Lapped surfaces
4. Nitralloy collar

13-32. In the diaphragm-type seal, shown in figure 18-9, which of the following sealing points is made at the factory?

1. Between the diaphragm and the crankcase
2. Between the fulcrum ring and the rotating shaft seal collar
3. Between the diaphragm and the fulcrum ring
4. Between the shaft seal collar and the crankshaft shoulder

13-33. Which of the following means is used to load compressors?

1. Oil pressure
2. Refrigerant pressure
3. Refrigerant suction
4. Water pressure

13-34. When does the compressor take on a load?

1. When the compressor is at 1/3 speed
2. When the compressor is at 1/2 speed
3. When the compressor is up to speed
4. When the compressor valve is closed

13-35. After the compressor has reached full speed, when does the capacity control system start to unload the compressor?

1. When the shaft seal bursts
2. When the system is overcharged
3. When the pulldown period is completed
4. When the pulldown period begins

13-36. In figure 18-10 of the textbook the working pressures that operate the hydraulic relay (C) are developed by the

1. spring and the control oil pressure
2. spring and the oil pump pressure
3. control oil pressure and the oil pump pressure
4. control oil pressure and the crankcase pressure

13-37. In figure 18-10 of the textbook, what forces piston (F) of the unloader power element E first up, then down?

1. Oil pump pressure; crankcase pressure
2. Oil pump pressure; spring
3. Crankcase pressure; spring
4. Spring; oil pump pressure

13-38. In figure 18-10 of the textbook, which of the following controls the amount of oil that reaches the unloader power element?

1. Hydraulic relay piston (D)
2. Lifting fork (G)
3. Suction valve (I)
4. Orifice

13-39. What is the result of the changes that take place in the R-12 on passing through the condenser?

1. It evaporates and, as a vapor, absorbs its latent heat of vaporization
2. It condenses and, as a liquid, gives off its superheat
3. It absorbs its latent heat of vaporization, evaporates completely, and in the vaporized state, absorbs sensible heat
4. It gives up its sensible heat, condenses and gives off its latent heat

13-40. When temperatures in the refrigerated space drop below the set point, the solenoid control valve (a) and the flow of refrigerant (b)

1. (a) opens, (b) stops
2. (a) closes, (b) stops
3. (a) opens, (b) starts
4. (a) closes, (b) starts

Items 13-41 through 13-44 pertain to the following control and safety devices:

A. Spring-loaded relief valve

B. Water regulating valve

C. Low-pressure cutout switch

D. Evaporator pressure regulating valve

E. High-pressure cutout switch

F. Water failure switch

G. Oil failure switch

13-41. If the pressure setting of the device is too low, water will freeze in a water cooler equipped with a

1. B
2. D
3. E
4. F

13-42. The compressor will stop when the pressure reaches cutout point and start when the pressure drops to reset point provided you correctly set the

1. B
2. C
3. D
4. E

13-43. The proper rate of cooling water flow through the condenser is maintained by the

1. A
2. B
3. D
4. F

13-44. What device will perform the intended function of F, if F fails to function?

1. A
2. B
3. C
4. E

13-45. What device in the refrigerant liquid line protects the solenoid valve and thermostatic expansion valves from foreign matter?

1. TXV
2. Liquid strainer
3. Dehydrator
4. Thermometer

13-46. Why is copper used to make refrigerator tubing for modern naval installations?

1. Copper internal surfaces are smooth enough to minimize friction
2. Copper is not corroded by refrigerant
3. Copper tubing is easily shaped to meet refrigeration requirements
4. For all the above reasons

13-47. Refer to textbook figure 18-19. The upper cavity of the packless valve is sealed off from the lower cavity by a

1. diaphragm
2. ball check
3. balancing port
4. lower stem

Learning Objective: Specify the procedures for starting, operating, and securing a refrigeration system. Textbook pages 405 through 408.

13-48. How often should a refrigeration system's temperatures and pressures be checked in the absence of specific instructions that state otherwise?

1. Hourly
2. Every 2 hours
3. Once each watch
4. Daily

13-49. When water is taken from a firemain, the pressure reducing valve ahead of the water regulating valve should be set so that the water pressure will NOT be more than

1. 15 psi
2. 25 psi
3. 35 psi
4. 45 psi

13-50. Before setting the controls on automatic, you should check the operating condition of the motor and compressor by

1. cracking the compression-suction valve
2. starting and stopping the unit several times
3. bringing the discharge pressure to 125 psi
4. checking the temperatures of the unit with all refrigerant system valves closed

13-51. Which of the following symptoms indicates that liquid refrigerant is being drawn into the compressor?

1. Frost on the compressor crankcase
2. Frost on suction valve
3. Unusual knocking of compressor
4. Each of the above

13-52. The condensing pressure of refrigeration systems equipped with water regulating valves should be maintained at

1. 50 to 60 psi
2. 125 psi
3. 100 to 110 psi
4. 175 psi

13-53. An R-12 refrigeration plant is supplied with cooling water from either a centrifugal pump or from the fire and flushing main. When, if ever, is the pump controller switch of this plant opened manually?

1. When cooling water is from the pump
2. When cooling water is from both the pump and the main
3. When cooling water is from the main
4. Never

13-54. When securing the compressor of an R-12 refrigeration system for a short period of time, you should first slowly close the

1. main liquid valve after the receiver to prevent a rapid fluctuation in suction pressure
2. water supply to the condenser to limit the quantity of water to the condenser
3. compressor suction valve to prevent a rapid reduction in crankcase pressure
4. compressor discharge shutoff valve to prevent a rapid increase in crankcase pressure

13-55. Why should two compressors serving the same cooling coil NOT be operated at the same time?

1. Because oil may be transferred from one compressor to another and cause serious damage
2. Because of the compressor discharge differential pressure
3. Because of the compressor motor electrical interlock
4. Because of all of the above

Learning Objective: Describe the types of maintenance and procedure required for a properly operating refrigeration system. Textbook pages 408 through 414.

13-56. An EN3 and EN2 are responsible for which of the following maintenance jobs on R-12 systems?

1. Purging a system of noncondensable gases
2. Testing for refrigerant leaks with a halide torch
3. Adjusting refrigeration system controls
4. All of the above

13-57. A recommended defrosting practice for effective cooling with the average cold-storage refrigeration installation is to defrost

1. daily
2. weekly
3. cooling coils before the average frost thickness reaches 3/16 inch
4. when the frost thickness at any location on the cooling coils is 1/2 inch or more

13-58. You are pumping down a system for minor repairs on lines between the receiver and cooling coils. Which of the following precautions should you observe before making repairs?

1. Blow out all R-12 gas from the isolated section that has been opened
2. Allow the lines to return to normal temperature after pumping them down and before opening them
3. Pump the lines down to a few pounds above atmospheric pressure before opening them
4. Cap removed sections of line to prevent loss of refrigerant from them

13-59. When you must pump down an entire refrigeration system for major repairs, you should begin the pumping operation by interrupting the flow of R-12 at the

1. compressor suction line stop valve
2. compressor discharge line stop valve
3. main liquid-line shutoff valve
4. cooling-coil solenoid valve

13-60. You are in the process of draining the refrigeration charge from a refrigeration system. What should you do after the compressor has been stopped by the low-pressure control switch?

1. Close the compressor discharge line valve
2. Close all liquid valves at the cooling coil
3. Connect an empty R-12 service drum to the refrigerant drain valve
4. Restart the compressor manually and continue pumping down until suction pressure reaches approximately 2 psig

13-61. Before connecting an R-12 service drum to the refrigerant drain valve, which of the following steps should you take?

1. Cool the drum to expedite draining
2. Weigh the drum to determine its capacity
3. Adjust the temperature of the drum to that of the refrigerant
4. Vent the drum to the atmosphere

13-62. When draining the refrigerant charge from the refrigeration system, what should you do to ensure that the service drum is NOT filled beyond rated capacity?

1. Measure the temperature
2. Measure the pressure
3. Weigh the drum
4. Both 2 and 3 above

13-63. After draining a refrigeration system, what should you do with the R-12 vapor remaining in the condenser and receiver?

1. Discharge it to the atmosphere
2. Condense and release it slowly
3. Compress and return it to the evaporator
4. Remove it by pumping air into the system

13-64. Which of the following conditions may indicate loss of refrigerant from a refrigerating system?

1. Short cycling
2. Frosting of the compressor suction line
3. Excessive lubrication oil pressure
4. Relatively low crankcase and cylinder temperatures

13-65. Normal operation of the halide leak detector in an atmosphere of air that is free of R-12 is indicated by a

1. yellow flame
2. blue flame
3. purple flame
4. green flame

13-66. What flame color in a halide leak detector indicates excessive quantities of R-12 in the air surrounding a leaking refrigerant system?

1. White
2. Yellow
3. Purple
4. Green

13-67. What should you do when the flame of the halide leak detector is yellow or white in color?

1. Hold the end of the exploring tube farther away from the joint being tested
2. Clean out the interior of the torch exploring tube
3. Adjust the reactor plate and make sure it is properly in place
4. Adjust the flame until a neutral or green color prevails

13-68. R-12 is being lost from a refrigerating system but you are unable to use the halide torch because of excessive R-12 in the atmosphere. What should you do?

1. Recharge the system to normal capacity
2. Pump down the system and apply compressed air through an atmosphere vent
3. Apply soapsuds to all joints in the system and look for bubbles
4. Apply light oil to all joints in the system and repeat the halide torch tests

13-69. When searching for leaks with the soap test, how long should you wait for bubbles to form from a small leak?

1. 15 seconds or less
2. 30 seconds or less
3. 45 seconds or less
4. 60 seconds or more

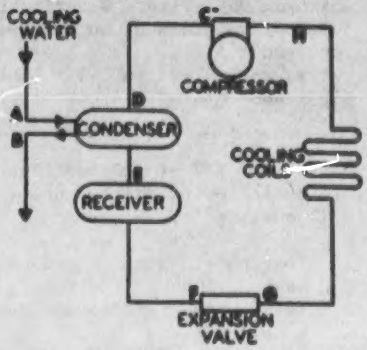

Figure 13B.—Simplified diagram of a refrigeration system.

13-70. How should you remove trapped noncondensable gases from the system shown in figure 13B?

1. Pump down the system and bleed off compressed liquid and gas at E
2. Open the line at F to the atmosphere while the system is operating
3. Stop the compressor and vent gases to the atmosphere at D
4. Briefly open the gage connection at C while the system is operating

13-71. You can determine whether the system shown in figure 18-13 contains excessive amounts of noncondensable gases by comparing the temperature at E with the pressure temperature at C. However, purging is necessary only when the difference between the two temperatures exceeds a maximum of

1. 1°F
2. 3°F
3. 5°F
4. 7°F

13-72. What is the correct procedure for checking the actual oil level in a force-lubricated compressor if oil has been added and it has been inoperative for several weeks?

1. Observe the oil level in the sight glass before starting the compressor
2. Operate the compressor on manual control for an hour or more and observe the oil level in the sight glass immediately after stopping the compressor
3. Stop the compressor and check the oil level with the crankshaft and connecting rod ends immersed in the lubricating oil
4. Stop the compressor and check the oil level with the crankshaft and connecting rod ends out of the lubricating oil

13-73. What should you do to remove oil from a compressor that has no drain valve?

1. Stop the compressor and close the suction and discharge line valves
2. Reduce crankcase pressure to about 1 psi by slowly closing the suction line stop valve
3. Loosen the drain plug just enough for oil to seep out
4. Do all of the above

13-74. On a refrigeration system with steel connections, how often should oil in a compressor crankcase be checked for contamination?

1. Annually
2. Every 3 months
3. Semiannually
4. Weekly

13-75. What should you do when one of the belts in a multiple V-belt drive is stretched excessively?

1. Replace the defective belt
2. Replace all the belts
3. Tighten the defective belt
4. Treat the defective belt with belt dressing

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Assignment 14

Refrigeration (Continued); Air Conditioning; Additional Auxiliary Equipment

Textbook Assignment: Pages 414 through 459

Learning Objective: Point out various operating ranges and procedures for setting controls and safety devices in refrigeration systems and indicate some of the operating features. Textbook pages 414 through 419.

14-1. What adjustment in the high-pressure switch will raise the cutout point without affecting the cut-in point?

1. Turning the range adjusting screw clockwise
2. Turning the range adjusting screw counterclockwise
3. Turning the differential adjusting screw clockwise
4. Turning the differential adjusting screw counterclockwise

14-2. You are in the process of adjusting the high-pressure switch of a refrigeration plant. What action do you take immediately after raising the compressor discharge to 10 psig above the desired cut-in pressure?

1. Turn the range screw clockwise until the contacts close
2. Turn the range screw counterclockwise until the contacts open
3. Turn the differential screw counterclockwise all the way
4. Turn the differential screw clockwise all the way

14-3. When setting the high-pressure switch, the differential switch is turned in which of the following directions?

A. Counterclockwise
B. Clockwise

1. B, A, B
2. A, B, A
3. B, A
4. A, B

14-4. You wish to set the low-pressure switch of a refrigeration plant so that it will cut out at 50 psig. With the compressor operating you should set the suction pressure to

1. 30 psig and turn the range screw clockwise until the switch contacts close
2. 50 psig and turn the range screw counterclockwise until the switch contacts open
3. 30 psig and turn the differential screw clockwise until the switch contacts close
4. 50 psig and turn the differential screw counterclockwise until the switch contacts open

14-5. The water failure switch is set properly when it cuts out at

1. 5 psig and cuts in at 15 psig
2. 10 psig and cuts in at 20 psig
3. 15 psig and cuts in at 5 psig
4. 20 psig and cuts in at 10 psig

14-6. Which of the following control devices is controlled by pressure changes that are brought about by changes in temperature in the refrigeration compartment?

1. Water failure switch
2. Thermostatic switch
3. Thermal expansion valve
4. Automatic reducing valve

14-7. If the refrigeration plant is NOT operating satisfactorily, what is normally the first step in checking the system?

1. Test the discharge valves
2. Test the suction valves
3. Shift the compressors
4. Short cycle the compressor

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14-8. When testing for a leaking discharge valve, which of the following are the first and last procedures?

A. Stop the compressor
B. Pump the compressor down to 2 psig
C. Close the suction and discharge valves
D. Check the rate of drop of discharge pressure

1. A, C
2. B, D
3. A, D
4. B, C

14-9. When a seal is being replaced on the compressor, why should the oil drain be left open?

1. To allow the oil to continue to drain
2. To prevent pressure buildup from R-12 in the oil
3. To prevent foaming of the oil
4. For each of the above reasons

14-10. After replacing a shaft seal on the compressor, how do you check for a leak?

1. Pump down the compressor and look for oil
2. Fill the crankcase and look for oil
3. Open the suction and discharge valves and check with a halide leak detector
4. By each of the above methods

Learning Objective: Identify the safety precautions to be taken when handling refrigerants. Textbook pages 419-421.

14-11. Gaseous R-12 is a health hazard because it

1. poisons on contact any food that contains milk or eggs
2. irritates the eyes unless it is diluted with at least an equal amount of air
3. will not support respiration
4. explodes when it come in direct contact with a high-temperature open flame

14-12. When R-12 comes in contact with an open flame or a high temperature, it becomes a health hazard. Which of the following is an indication of this condition?

1. A pungent odor
2. An irritant to breathing
3. Both 1 and 2 are correct
4. The smell of new mown hay

14-13. What percentage of capacity is the limit to which an R-12 cylinder should be filled?

1. 75%
2. 80%
3. 85%
4. 90%

14-14. Which of the following articles of safety gear must you wear when working with R-12?

1. Apron and gloves
2. Goggles
3. Mouthpiece
4. All of the above articles

14-15. What first-aid treatment should you administer in case R-12 comes in contact with your skin?

1. Rub or massage the affected area
2. Immerse the affected part in a warm bath
3. Apply nonirritating oil to the affected skin
4. Bathe the affected area with strong soap and water

Learning Objective: Specify the purpose of air conditioning, identifying the various principles affecting its efficiency. Textbook pages 422-426.

14-16. In addition to contributing to the comfort and fitness of the crew aboard ship, air conditioning also performs which of the following?

1. Prevents deterioration of ammunition in storage spaces
2. Maintains temperature at specified levels in electrical and electronic equipment spaces
3. Prevents excessive pressure buildup in containers in gas storage spaces
4. Does all of the above

14-17. The dewpoint of air is defined as the temperature at which

1. the specific humidity is 100 grains per pound of dry air
2. the air is saturated with moisture
3. any increase in temperature will cause moisture to condense
4. dew vaporizes into the air

14-18. Which condition will occur if the temperature of the air increases while the amount of moisture in the air remains constant?

1. The specific humidity will increase
2. The specific humidity will decrease
3. The relative humidity will increase
4. The relative humidity will decrease

14-19. The relative humidity of air is the ratio between the actual amount of water vapor in a sample of air and the

1. weight of the sample
2. volume of the sample
3. amount of water vapor the sample would hold if it were saturated
4. dewpoint of the sample

14-20. Which atmospheric condition can be directly measured with a sling psychrometer?

1. Latent heat
2. Dewpoint
3. Wet-bulb temperature
4. Specific humidity

14-21. From what source does most of the body heat come?

1. Surroundings that radiate heat
2. Currents of heated air
3. Physiological processes within the body
4. Objects that transmit heat by contact

14-22. The loss of latent heat from the human body is by

1. evaporation
2. radiation
3. conduction
4. convection

14-23. What type of heat loss is directly associated with being exposed to circulating air?

1. Radiation
2. Convection
3. Conduction
4. Evaporation

14-24. The quantity of heat that will be given off by a group of 20 sailors seated in a classroom will average about

1. 5,800 Btu per hour
2. 6,400 Btu per hour
3. 7,000 Btu per hour
4. 7,600 Btu per hour

14-25. When you remain stationary in a space where the air is perfectly still, what happens to the envelope of air that surrounds your body?

1. It absorbs water vapor from your body
2. Its relative humidity increases
3. Its temperature increases
4. All of the above

14-26. What is the best range of relative humidity for health conditions and comfort in a cold climate?

1. 30 to 40%
2. 40 to 50%
3. 50 to 60%
4. 30 to 70%

Learning Objective: Identify the construction and function of typical ventilation and cooling equipment. Textbook pages 426-437.

14-27. Vane-axial ventilating fans should be operated with the air ducts open so that

1. less electrical current will be used
2. a large volume of air can be heated at low pressures
3. the motors will not overheat
4. air distribution can be limited

14-28. How is water kept from entering a duct system when, due to heavy seas, water enters the bucket of a waterproof ventilator faster than the bucket can drain off?

1. On reaching a prescribed depth, water in the bucket actuates the gear which closes the ventilator
2. On reaching a prescribed depth, water in the bucket trips a lever which allows the buckets to empty onto the deck
3. As water rises in the bucket, more tubes take part in emptying the bucket through scuppers
4. The weight of water in the bucket lowers the bucket and seals off the system

14-29. Cool dry air blown into a compartment by a refrigeration system cools the compartment by

1. raising the humidity
2. holding the humidity at a constant level
3. forcing the warm air out
4. absorbing heat and moisture from the air

14-30. Compared to air conditioning systems, refrigeration systems have suction pressures and evaporator temperatures that are

1. higher
2. lower
3. about equal
4. higher and lower, respectively

14-31. In the vapor compression chilled-water system, where is the heat removed from the secondary refrigerant?

1. In the water chiller
2. In the condenser
3. In the refrigerant receivers
4. In the float chambers

14-32. In a centrifugal refrigeration plant, what releases the refrigerant to the chiller?

1. Compression valve
2. Suction valve
3. Float valve
4. Differential compression valve

14-33. When water leaves the cooler of a chilled water circulating system, it has a temperature of

1. 35° to 40°F
2. 40° to 45°F
3. 45° to 50°F
4. 50° to 55°F

14-34. In a refrigerating system that has a centrifugal compressor, what pressure actuates the high-pressure switch?

1. High condenser pressure
2. Low lube oil pressure
3. Evaporator pressure
4. Seawater pressure

14-35. The centrifugal refrigeration control device which depends on seawater pressure for its functioning is called a

1. chilled-water pressure failure switch
2. condenser water pressure failure switch
3. chilled-water temperature control switch
4. high-pressure switch

14-36. Oil heaters are used when the compressor is off. What is the purpose of the oil heater?

1. To heat the oil when the compressor is on standby
2. To prevent refrigerant from entering the oil
3. To reduce viscosity of the oil
4. To do both 2 and 3 above

14-37. The first-stage impeller of a centrifugal refrigerating compressor performs all EXCEPT which of the following functions?

1. Drawing vapor into the compressor
2. Compressing vapor drawn into the compressor
3. Discharging compressed vapor to the second-stage impeller
4. Discharging compressed vapor to the condenser

14-38. Instead of a thermal expansion valve, many packaged unit air conditioners are fitted with

1. float valves
2. economizer chambers
3. adjustable high-pressure switches
4. capillary tubes

14-39. Which of the following components of a package unit air conditioner can you adjust after it is installed?

1. High-pressure switch
2. Low-pressure switch
3. Water-regulating valve
4. Thermal expansion valve

14-40. When a fan-coil assembly is installed in a ship, it is used in conjunction with a

1. packaged unit air conditioner
2. refrigerant-circulating air conditioning system
3. refrigerant-circulating refrigeration system
4. chilled-water circulating system

14-41. What feature of a fan coil assembly permits a change of capacity?

1. Cooling coil bypass
2. Belt drive of the centrifugal fan
3. Adjustable damper
4. Removable end panels

Learning Objective: Describe the construction and function of air heating equipment. Textbook pages 437-442.

14-42. Why is the T-type coil arrangement used instead of the S-type in large size ventilation heaters?

1. T-type weighs less
2. T-type occupies less space
3. T-type is more efficient
4. T-type has fewer tubes

14-43. During cold weather operations, reheaters in large recirculating cooling systems serve to

1. keep certain spaces and zones at specified temperatures
2. prevent condensation in the ducts leading to engineering spaces
3. set up temperature differentials at different levels in a room
4. supplement the heating capacity of the convector heaters

14-44. Convector heaters and unit heaters may be used in all EXCEPT which of the following heating systems?

1. Forced hot water system
2. 200-psi steam system
3. 100-psi steam system
4. 50-psi steam system

14-45. What type of thermostat is used to control the flow of steam to preheaters?

1. Type C
2. Type L
3. Type R
4. Type W

14-46. Which combination of thermostat assembly and valve assembly is used in the temperature regulator that controls the flow of steam to a combination heater?

1. Type L thermostat, model D valve
2. Type L thermostat, model E valve
3. Type R thermostat, model D valve
4. Type W thermostat, model G valve

14-47. The temperature of a ventilation preheater coil is prevented from falling to the freezing point by a thermostatic control that allows steam to pass through the regulating valve when the temperature in the duct on the weather side of the heater falls to

1. 32°F
2. 35°F
3. 38°F
4. 41°F

14-48. What kind of information can be found on the valve bonnet of a thermostatic assembly?

1. Length of tube
2. Operating temperature of the motor bellows
3. Steam pressure and poppet number
4. All of the above

Learning Objective: Identify key points in the maintenance of ventilation equipment. Textbook page 444.

14-49. In a complete air conditioning system, the shipboard ventilation system and its constituent parts should be isolated from other component systems.

14-50. Why should dirt be kept out of a ventilation system?

1. It restricts airflow
2. It creates a fire hazard
3. It does both 1 and 2 above
4. It damages the filters

Learning Objective: Describe the layout and operation of electrohydraulic steering gear, including maintenance procedures. Textbook pages 445 and 456.

14-51. The amount of oil that the A-end of an electrohydraulic drive delivers to the B-end is regulated by means of a

1. socket ring
2. rack-and-pinion assembly
3. tilt box
4. synchronous receiver

14-52. An electrohydraulic drive which was designed to transmit rotary motion is to be used to move a ship's rudder. Which part of the drive will be replaced by a piston?

1. Electric motor
2. Hydraulic motor
3. Hydraulic pump
4. Tilt box

14-53. Assume that your ship is running before a gale and the following seas produce heavy strains on the rudder. What mechanism of a double-ram electrohydraulic steering gear eases the excessive strain on the system?

1. Rudder
2. Variable stroke pump
3. Tilting boxes
4. Relief valve

14-54. In an electrohydraulic steering gear, the standby pump is brought into operation by the

1. idle motor
2. running motor
3. relief valve
4. six-way plug cock

14-55. The steering gears of most modern naval ships are remotely controlled from the bridge through the use of a/an

1. a.c. synchronous transmission system
2. hydraulic telemotor system
3. d.c. pilot-motor
4. mechanical linkage

14-56. The receiver motor in an a.c. synchronous transmission steering system turns at one-half the speed of the transmitter rotor in the system.

14-57. In the hydraulic steering assembly, which component connects the plunger to the mechanical linkage from the steering gear control mechanism?

1. Remote receiver element
2. Electrohydraulic steering connecting block
3. Electrohydraulic power receiver
4. Crosshead

14-58. The pistons of a reversible axial piston pump are on stroke at all times because the socket ring is set at a fixed angle.

14-59. When a steering wheel is turned, what force produces a movement of the receiver plungers in the telemotor system?

1. Electrical power
2. Fluid pressure
3. Air pressure
4. Steam pressure

14-60. When a telemotor system is being filled, pumping is continued until the

1. forward telemotor is open
2. oil is free of bubbles
3. oil appears at the air cocks
4. replenishing tank is full

14-61. A leak is stopped in an externally packed telemotor by

1. tightening the glands
2. loosening the glands
3. tightening the leathers
4. loosening the leathers

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14-62. When a telemotor system is exposed to low ambient temperatures, an oil with what pour point should be used?

1. -25°F to 40°F
2. -25°F to -40°F
3. 2°F to 75°F
4. 2°F to 150°F

14-63. By installing guards around the exposed parts of the steering gear rams you can protect the parts against water damage and rust.

14-64. Which of the following duties is performed by an Engineman standing watch in the steering engineroom?

1. Checking the oil level in the expansion tank
2. Feeling with his bare hands for hot parts in the steering gear
3. Bleeding air out of the hydraulic system
4. Each of the above

14-65. Clearance between the brake drum and band increase after a windlass has been operating for a period of time.

14-66. When performing maintenance work on hydraulic transmissions, which of the following steps must you always take?

1. Use a strainer when refilling tanks with clean oil
2. Clean internally all valves and piping that have been disassembled
3. Clean all parts before reassembling them
4. Do all of the above

Learning Objective: Point out maintenance procedures for winches and capstans and describe cranes and their controls. Textbook pages 456 through 459.

14-67. In maintaining capstans and winches, which of the following inspections should be conducted?

1. Check for oil or grease on drums and linings
2. Check the deterioration of friction clutch linings
3. Check the load-holding ability of shifting-gear locking devices
4. Do each of the above

14-68. Which crane classification is NOT included in the general types?

1. Stationary king post
2. Hand operated
3. Traveling
4. Jib

14-69. The boom of a crane is controlled by the

1. king post
2. blocks
3. rotating gear
4. sheaves

14-70. To prevent fouling of the hoisting rope, a crane is provided with

1. fair-lead sheaves
2. blocks
3. a king post
4. a grooved drum

14-71. The delicate control often required for handling loads with a crane is usually provided by

1. an electric motor for rotating the crane
2. reduction gearing in the crane rotating mechanism
3. hydraulic variable-speed gears for driving the hoisting whips and topping lifts
4. electric motors for driving the hoisting whips and topping lifts

14-72. The hoisting units of a crane are driven by

1. constant-speed electric motors
2. variable-speed electric motors
3. B-end hydraulic motors
4. A-end hydraulic pumps

14-73. What device on a crane is provided to hold the load when electric power fails?

1. A-end hydraulic pump
2. Hydraulic torque motor
3. Hand brake
4. Electric brake

14-74. The neutral position of the A-end hydraulic pump on a crane is found and retained by

1. a B-end hydraulic motor
2. a centering device
3. an electric torque motor
4. a slack-takeup device

14-75. When a crane is used to raise light loads, the cable has a tendency to develop slack when hoisting is started. To prevent slack, the crane is provided with a/an

1. electric torque motor
2. hydraulic torque motor
3. light-hook paying-out device
4. pressure stroke control device

Assignment 15

Additional Auxiliary Equipment (Continued) and Lathes and Lathe Machinery

Textbook Assignment: Pages 459 through 504

Learning Objective: Identify the principles of operation and maintenance procedures required for proper operation of galley equipment. Textbook pages 459 through 464.

15-1. The primary concern of an Engineman for the maintenance of steam cooking equipment is the

1. cookers
2. full-floating doors
3. steam jacket
4. valves or piping

15-2. In a single-tank dishwasher, the washing and rinse sprays differ in temperature and are controlled by separate valves.

15-3. In a double-tank dishwasher, the final rinse is activated by

1. manual control
2. a thermostat control
3. the movement of dish racks
4. a cam on the conveyor belt

15-4. The rinse tank of a double-tank dishwashing machine contains a thermostatically operated switch which prevents machine operation if the temperature of the rinse water drops below

1. 180°F
2. 190°F
3. 200°F
4. 210°F

15-5. You are preparing to descale a dishwasher whose tanks have a capacity of 36 gallons. How much orthophosphoric acid 85% and detergent, respectively, do you add to the water in each tank to make up the proper cleaning solution?

1. 7 fluid ounces; 18 fluid ounces
2. 18 fluid ounces; 36 fluid ounces
3. 126 fluid ounces; 9 fluid ounces
4. 252 fluid ounces; 18 fluid ounces

15-6. When descaling, after operating a dishwasher with cleaning solution in its tanks for 60 minutes, what should you do?

1. Repeat the cleaning procedure with a fresh cleaning solution
2. Drain the cleaning solution and rinse the tanks several times with fresh hot water
3. Drain the cleaning solution and rinse the tanks for 5 minutes; first with hot water and then with cold water
4. Drain the cleaning solution, rinse thoroughly with cold water and blow dry with air under pressure

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Learning Objective: Identify auxiliary boilers and their controls. Textbook pages 464 through 470.

15-7. In a water tube natural-circulation boiler, the large tubes located at the front and rear ends of the water and steam drum that connect with each drum are referred to as

1. generating tubes
2. water-wall tubes
3. downcomers
4. coils

15-8. Whereas natural-circulation boilers depend upon a difference in the density of rising and falling fluids for circulation, forced-circulation boilers circulate their fluids with the help of pumps.

15-9. The amount of oil that is atomized by a variable capacity atomizer depends upon the

1. amount of air admitted to the atomizer and the oil supply pressure
2. amount of air admitted to the atomizer and the oil pressure in the oil return line
3. difference between the amount of oil entering the atomizer and the amount leaving it
4. size of orifice plate installed and the oil pressure in the supply line

15-10. What unit of a variable capacity atomizer assures that there will be the correct combination of air and oil while the burner is operating?

1. Oil metering valve linked with an air admitting regulator
2. Pressure regulating mechanism linked to atomizer nut
3. Sprayer plate linked to orifice plate
4. Pump linked with air bellows

15-11. If the water level electrode assembly in textbook figure 20-18 is working properly, the feed pump starts automatically when the water level reaches the

1. low end of electrode 1
2. low end of electrode 2
3. low end of electrode 3
4. inner surface of the boiler shell

15-12. Which of the following regulating devices employs a bellows arrangement?

1. Float-type feedwater regulator
2. Limit pressuretrol
3. Stack switch
4. Constant pressure governor

15-13. When modulating pressuretrols are used to automatically regulate burner firing rates as boiler loads change, the air-oil ratios for the burners are adjusted by a mechanism linked to and operated by a reversing-type motor.

15-14. Which of the following types of control devices responds directly to changes in temperature?

1. Limit pressuretrol
2. Stack switch
3. Electrode-type feedwater control
4. Photoelectric safety combustion control

Learning Objective: Test boiler feedwater. Textbook pages 470 through 474.

15-15. What publication should you consult for detailed instructions on testing boiler water for alkalinity, hardness, and chloride content?

1. NAVSHIPS' Technical Manual
2. The manufacturer's technical manual for your ship's boilers
3. The manual accompanying a Taylor comparator
4. Any of the above

15-16. In preparing a sample of boiler water for an alkalinity test, you should make sure that the water meets which of the following conditions?

1. It was allowed to stand in an open container for 4 hours or more
2. It was not exposed to air long enough to absorb carbon dioxide
3. It was heated to its boiling point
4. It was allowed to stand until its temperature dropped below 100°F

15-17. A burette reading is made from the top of the meniscus, at the surface of the liquid.

15-18. If soap and water will not properly clean the chemical glassware and porcelain used in testing boiler water, cleaning should be done with a solution of

1. lye and water
2. alcohol and scouring powder
3. weak acid
4. alcohol and distilled water

15-19. Both the phenolphthalein test and the methyl-purple test for alkalinity should be used on water from

1. boilers that have been idle for a long time
2. freshly filled boilers that have not been steamed
3. idle boilers that have been steamed
4. steaming boilers

15-20. Adding phenolphthalein indicator to an alkaline solution causes the solution to turn

1. green
2. purple
3. greenish-gray
4. pink

15-21. When running an alkalinity test on a sample of boiler water that has been steamed, what agent do you add to cause the pink color to disappear?

1. Phenolphthalein solution
2. Nitric acid
3. Mercuric nitrate
4. Methyl-purple solution

15-22. What technique should you apply in testing the alkalinity of water in an unsteamed boiler if the water is not clear enough for the methyl-purple test?

1. Carry out a chloride test and divide the result by two
2. Carry out a phenolphthalein test and multiply the result by two
3. Use the Taylor comparator, conduct separate pH and phosphate tests, and average the results
4. Let the sample settle; then retest

15-23. Assume that you have added to a sample of water an amount of soap equal to the lather factor. How long should the lather cover the surface of the sample to indicate zero hardness?

1. At least 2 minutes
2. At least 5 minutes
3. At least 15 minutes
4. At least 25 minutes

15-24. When running a hardness test on boiler water, you require 0.8 ml of soap solution to maintain an unbroken surface of suds on the sample. What is the hardness of the sample?

1. 0.02 epm
2. 0.04 epm
3. 0.06 epm
4. 0.08 epm

15-25. In the chloride test, what color should the sample of water be when the blue-violet color vanishes?

1. Gray
2. Pink
3. Red
4. Yellow

Learning Objective: Describe the operating procedures for the P-250 fire pump. Textbook pages 474 and 475.

15-26. While operating a P-250 pump, you notice that an uneven stream is coming out of the nozzle. What would you expect to be the most likely cause of this condition?

1. Air leakage into the suction side of the pump
2. Insufficient outlet pressure
3. Insufficient power from the motor
4. Excessive pump speed

15-27. To start a P-250 pump, the next step after connecting the fuel hose to the plug on the control panel from the fuel tank is to

1. pull the choke knob to the extended position
2. fill the gasoline tank with 1/2 pint SAE 30 engine oil to each gallon of gasoline
3. fill the line to the carburetor by pressing the push button on the tank several times until you feel some resistance
4. turn the high and low speed knobs on the control panel three-quarters of a turn counterclockwise from the closed position

15-28. Suppose that after starting a P-250 pump, you notice that water pressure is NOT building up on the gage. What should you do?

1. Increase the pump speed by adjusting the throttle
2. Decrease the pump speed by partially closing the throttle
3. After the pump has operated for not more than 45 seconds, stop the engine, tighten hose connections and couplings, and prime again
4. Allow the pump to operate for 1 minute, then stop engine and prime again.

Learning Objective: Identify principal characteristics of the engine lathe. Textbook pages 477 through 481.

15-29. When a workpiece is being shaped with a cutting tool on an engine lathe, it is held and rotated about a horizontal axis.

15-30. The engine lathe in a machine shop can be used for which of the following jobs?

1. Turning and boring
2. Facing and screw cutting
3. Drilling and grinding
4. All of the above

15-31. In ships, which have only one lathe, what is usually the size of the lathe?

1. 14 in.
2. 16 in.
3. 18 in.
4. 20 in.

15-32. On a lathe equipped with a 6-position headstock cone pulley, how many spindle speeds can be obtained?

1. 6
2. 12
3. 18
4. 24

15-33. When an engine lathe is used for milling, the workpiece is usually mounted on the

1. headstock and tailstock centers
2. tailstock spindle
3. carriage
4. face plate

15-34. On an engine lathe, which of the following operations is usually performed with the carriage locked in position?

1. Turning
2. Facing
3. Boring
4. Drilling

15-35. Gears in the apron of an engine lathe are driven by the

1. control rod
2. lead screw
3. reverse rod
4. feed rod

15-36. When an engine lathe is used for thread cutting, the number of threads per inch is determined by the relationship between the speeds of the

1. drive motor and spindle
2. spindle and feed rod
3. lead screw and feed rod
4. lead screw and spindle

15-37. A lathe operator is able to feed a cutting tool at one desired angle to the lathe axis by using the compound rest.

Learning Objective: Describe correct shapes and applications of the principal cutting tools. Textbook pages 482 through 484.

15-38. Which cutter bit is sometimes ground flat on top so it may be fed in both directions?

1. Left-hand turning tool
2. Right-hand facing tool
3. Square-nosed parting tool
4. Round-nose turning tool

15-39. The square-nosed parting tool is used to

1. face on the left-hand side of lathe work
2. machine necks, grooves, and corners
3. take light roughing cuts and finishing cuts
4. hold small work for machining in the lathe

15-40. Which lathe tool is usually ground in the shape of a left-hand turning tool?

1. Threading tool
2. Round-nosed turning tool
3. Cut-off tool
4. Boring tool

Learning Objective: Recognize lathe chucks in terms of their capabilities and applications. Textbook pages 484 through 487.

15-41. What type of lathe chuck may be used to hold workpieces that have irregular cross sections?

1. Scroll chuck
2. 4-jaw chuck
3. Standard collet chuck
4. Hexagonal collet chuck

15-42. What type of lathe chuck can be used to center, automatically, round workpieces of many sizes?

1. Scroll chuck
2. 4-jaw chuck
3. Standard collet chuck
4. Hexagonal collet chuck

Learning Objective: Describe basic lathe operating procedures. Textbook pages 487 through 503.

15-43. When a second cut is made on a threaded workpiece, what does the thread dial indicator tell the operator?

1. Where to start the second cut
2. When to engage the lead screw
3. When the correct depth of cut has been reached
4. When the lead screw is rotating at the proper speed

15-44. A carriage stop may be used on an engine lathe to eliminate the need for which of the following actions?

1. Individual measurements on duplicate parts
2. Manually shutting off the automatic feed
3. Setup measurements made directly on the workpiece
4. Variable rates of feed across a workpiece

15-45. When large changes are made by shifting the gears in the main gear train, the lathe must be stopped.

15-46. What is the first requirement of a lathe operator with respect to maintenance of the engine lathe?

1. Lubricating properly the headstock only
2. Lubricating properly all moving parts
3. Keeping the ways clean and dry
4. Keeping the lead screw clean and dry

15-47. Which of the following steps must be taken before the longitudinal feed of a lathe is engaged?

1. Disengage the spindle clutch
2. Loosen the stop screw
3. Loosen the carriage clamp screw
4. Set the thread dial indicator to zero

15-48. The time required to perform a rough turning operation can often be shortened by reducing the

1. cutting speed and increasing the feed
2. depth of cut
3. longitudinal feed and increasing cutting speed
4. lubricant flow

15-49. Which lubricant is most likely to be used for general machine work on brass or monel rods?

1. Soda water
2. Turpentine
3. Dry or soluble oil
4. White lead

15-50. Normally, what is the direction of feed of a facing cutter?

1. Toward the apron
2. Toward the tailstock
3. Toward the lathe center
4. Away from the lathe center

15-51. Burrs in the tailstock spindle of a lathe should be removed with a

1. grinder
2. tail center coated with lapping compound
3. 60° taper reamer
4. Morse taper reamer

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15-52. Lathe centers may be positively aligned without making a test cut by using a

1. test bar and indicator
2. center gage
3. Morse taper gage
4. steel rule between the centers

15-53. Which of the following problems commonly results from excessive tool overhang?

1. Excessive depth of cut
2. Erratic feed
3. Tool chatter
4. Reduced cutting speed

15-54. When mounted work rests firmly between lathe centers, the tail of the driving dog is located

1. beyond the center of the tailstock
2. even with the base of the tailstock
3. rests on the base of the faceplate slot
4. beyond the base of the faceplate slot

15-55. The centering of rough work in a 4-jaw independent chuck should be checked by

1. taking a light test cut
2. holding a piece of chalk against the rotating work
3. bringing the tail center against the face of the work
4. locating the axis of the cylindrical portion with a combination square

15-56. Which of the following precautions should you take when chucking a thin-walled cylinder in a lathe?

1. Insert paper or shim stock under the chuck jaws
2. Expand the chuck jaws against the bore of the work
3. Use only enough jaw pressure to prevent slipping
4. Adjust the jaws individually to prevent distortion

15-57. What lathe accessory is used for mounting odd-shaped workpieces that cannot be turned between centers?

1. Mandrel
2. 3-jaw chuck
3. Collet chuck
4. Faceplate

15-58. The center rest is used for supporting long slender work held between ends to prevent springing and tool chatter.

15-59. The follower rest is adjusted to the size of the finished work and provides support against the cutting force as it moves with the carriage.

15-60. When work is held in a collet chuck for precise machining, the diameter of the work should not exceed the collet diameter by more than

1. 0.00001 in.
2. 0.0001 in.
3. 0.001 in.
4. 0.002 in.

15-61. When a facing cut is made in a workpiece on an engine lathe, which of the following feeds moves the tool?

1. Cross feed
2. Longitudinal feed
3. Compound-rest feed
4. Both 2 and 3 above

15-62. A depth of cut of 0.040 inch reduces the diameter of a lathe workpiece by

1. 0.020 in.
2. 0.040 in.
3. 0.080 in.
4. 0.120 in

15-63. Shoulders are commonly located with a parting tool to eliminate the need for

1. using a pointed turning tool
2. facing the shoulder
3. cutting a fillet
4. measuring during the rough turning

15-64. Which process is used to bring a hole to finished size when high accuracy is required?

1. Boring
2. Coring
3. Drilling
4. Reaming

15-65. Which of the following workpieces and tailstock setups produces the steepest taper per foot?

1. 1/8-inch setup with a 6-inch workpiece
2. 3/8-inch setup with an 8-inch workpiece
3. 5/8-inch setup with an 8-inch workpiece
4. 7/8-inch setup with an 8-inch workpiece

15-66. In which method for turning tapers on a lathe does the cutting tool move at an angle to the work and parallel to the lathe axis?

1. Using the compound rest
2. Using the taper attachment
3. Either 1 or 2 above
4. Setting over the tailstock

15-67. What method is normally used to cut large angles of taper on short workpieces?

1. Taper-attachment method
2. Compound-rest method
3. Offset-center method
4. Simultaneous-feed method

15-68. What instrument is used to obtain accurate angular settings of the compound rest?

1. Steel rule
2. Micrometer
3. Vernier bevel protractor
4. Center gage

15-69. When a taper attachment is used with a lathe, the depth of cut is adjusted with the

1. shoe clamp
2. cross-feed screw
3. compound-rest feed screw
4. longitudinal feed screw

15-70. The boring of a blind tapered hole is usually preceded by

1. taper reaming
2. drilling to the small diameter of the taper
3. drilling to slightly less than the small diameter of the taper
4. drilling to the large diameter of the taper

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